3GPP TR 36.888 V2.1.1 (2013-06)

Technical Report

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Study on provision of low-cost MTC UEs based on LTE;
(Release 12)

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Keywords
MTC, M2M, LTE, GSM, GPRS, UE

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Contents

Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

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Introduction

Machine-Type Communication (MTC) is an important revenue stream for operators and has a huge potential from the operator perspective. There are several industry fora working on an efficient M2M system with some industry members developing a new access technology dedicated for MTC. However, it is more efficient for operators to be able to serve MTC UE using already deployed radio access technology. Therefore it is important for operators to understand whether LTE could be a competitive radio access technology for efficient support of MTC. It is envisaged that MTC UE's will be deployed in huge numbers, large enough to create an eco-system on its own. Lowering the cost of MTC UE's is an important enabler for implementation of the concept of "internet of things". MTC UE's used for many applications will require low operational power consumption and are expected to communicate with infrequent small burst transmissions.

In addition, there is a substantial market for the M2M use cases of devices deployed deep inside buildings which would require coverage enhancement in comparison to the defined LTE cell coverage footprint.

This TR captures various features and their modifications to reduce cost and improve coverage along with various hardware simplifications that will enable production of low-cost MTC UE's. EGPRS multi-slot class 2 is assumed as a benchmark for cost comparison and minimum data rate capability.

1 Scope

As LTE deployments evolve, operators would like to reduce the cost of overall network maintenance by minimising the number of RATs. Machine-Type Communications (MTC) is a market that is likely to continue expanding in the future. Many MTC UE's are targeting low-end (low average revenue per user, low data rate) applications that can be handled adequately by GSM/GPRS. Owing to the low-cost of these devices and good coverage of GSM/GPRS, there is very little motivation for MTC UE suppliers to use modules supporting the LTE radio interface. As more and more MTC UE's are deployed in the field, this naturally increases the reliance on GSM/GPRS networks. This will cost operators not only in terms of maintaining multiple RATs, but it will also prevent operators from reaping the maximum benefit out of their spectrum (given the non-optimal spectrum efficiency of GSM/GPRS). Given the likely high number of MTC UE's, the overall resource they will need for service provision may be correspondingly significant, and inefficiently assigned.

Therefore, it is necessary to find a solution to ensure that there is a clear business benefit to MTC UE vendors and operators for migrating low-end MTC UE's from GSM/GPRS to LTE networks.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TS 36.306: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio access capabilities; Release 10".

[3] 3GPP TS 45.912: "Feasibility study for GSM/EDGE Radio Access Network (GERAN)".

[4] R1-120008: "Email Discussion Summary on Coverage Issues Identification".

[5] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures; Release 10".

[6] R1-080614: "Half Duplex FDD Operation in LTE", RAN1#51bis, Seville, Spain, January 2008.

[7] RP-111776: "Enhanced downlink control channel(s) for LTE".

[8] R1-122527: "Analysis and evaluation of reduction of supported downlink transmission modes", RAN1 #69, Prague, Czech Republic, 21st-25th May 2012.

[9] R1-122055: "Discussion on reduction of supported downlink transmission modes for low-cost MTC LTE UEs", RAN1 #69, Prague, Czech Republic, 21st-25th May 2012.

[10] R1-122117: "Evaluation/analysis on reduction of supported downlink Transmission Modes and Text Proposal", RAN1 #69, Prague, Czech Republic, 21st-25th May 2012.

[11] R1-122431: "Analysis of reduction of supported downlink transmission modes for low-cost MTC", RAN1 #69, Prague, Czech Republic, 21st-25th May 2012.

[12] R1-122638: "Discussion on reduction of supported downlink transmission modes for low-cost MTC UEs", RAN1 #69, Prague, Czech Republic, 21st-25th May 2012.

[13] R1-122169: "Analysis of transmission mode support for MTC devices", RAN1 #69, Prague, Czech Republic, 21st-25th May 2012.

[14] R1-122263: "Reduction of downlink transmission modes for MTC devices", RAN1 #69, Prague, Czech Republic, 21st-25th May 2012.

[15] R1-122280: "Analysis of Spatial Multiplexing Processing Reduction", RAN1 #69, Prague, Czech Republic, 21st-25th May 2012.

[16] R1-123072: "E-mail discussion summary for TP to clause 7 of 3GPP TR 36.888", RAN1 #69, Prague, Czech Republic, 21st-25th May 2012.

[17] RP-121441: "Updated SID on: Study on Provision of low-cost MTC UEs based on LTE"

[18] 3GPP TR 36.824: "Evolved Universal Terrestrial Radio Access (E-UTRA); LTE coverage enhancements".

[19] 2011 Census: Population and household estimates for England and Wales http://www.ons.gov.uk/ons/rel/census/2011-census/population-and-household-estimates-for-england-and-wales/rft-h01.xls

[20] TOKYO STATISTICAL YEARBOOK http://www.toukei.metro.tokyo.jp/tnenkan/tn-eindex.htm

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1] and the following apply.
A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

For the purposes of the present document, the term "Category 1 LTE UE" is also referred to as "normal LTE UE".

3.2 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply.
An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

MTC UE/Device: an UE equipped for Machine Type Communication

NOTE: In the scope of this TR , an MTC UE communicates with an Access Network capable of multiple cells with different characteristics (e.g., e-NodeBs, Home e-NodeBs, e-UTRA Relays).

4 Objectives of study

Solutions using, or evolved from, LTE RAN specifications up to and including Rel-10 shall be investigated and evaluated to clearly understand the feasibility of creating a type of terminal that would permit the cost of terminals tailored for the low-end of the MTC market to be competitive with that of GSM/GPRS terminals targeting the same low-end MTC market with improved coverage.

The study shall evaluate at least the following aspects:

- Benefit of developing methods for reducing RF component cost in the devices, including (for example) simplifications and reductions in support of bands/RATs/RF chains/antenna ports, transmission power, maximum channel bandwidth less than the maximum specified for respective frequency band, and support of half-duplex FDD mode.
- Benefit of developing methods for reducing the processing in the device, additionally considering baseband-RF conversion aspects, significantly lower peak data rate support, no support of spatial processing mode in uplink/downlink, and reduced radio protocol processing.
- A method to guarantee that any features recommended as part of this study to allow cost reduction, but which also bring a reduction in LTE system performance, shall be restricted to devices which only operate as MTC devices not requiring high data rates and/or low latency, after further careful study.
- Impact to the system spectral efficiency from techniques that allow coverage improvement techniques up to the target improvement figure - considering that a relatively small proportion of traffic requires the coverage improvement and the traffic can be scheduled at quiet times.
- In identifying solutions, any other related work agreed for Rel-12 should be taken into account.

As part of the analysis of the different solutions, any impacts on backwards compatibility with existing LTE network shall be evaluated and justified, as well as impact on the operation of legacy LTE Release 8-10 UEs and Release 8-10 LTE system performance.

NOTE: This study assesses, from a 3GPP standpoint, the technical feasibility of low-cost LTE devices for MTC. Given that factors outside 3GPP responsibility influence the cost of a modem/device, this study item (and the text above) cannot guarantee, or be used as a guarantee, that such modem/device will be low-cost in the market.

5 Requirements and methodology

5.1 Requirements

Solutions studied for provisioning of low-cost MTC UE based on LTE should support below as a minimum requirement.

- Support data rates equivalent to that supported by [R'99 E-GPRS] with an EGPRS multi-slot class 2 device (2 downlink timeslots (118.4 Kbps), 1 uplink timeslots (59.2 Kbps), and a maximum of 3 active timeslots) as a minimum. This does not preclude the support of higher data rates provided the cost targets are not compromised.

- Enable significantly improved average spectrum efficiency for low data rate MTC traffic compared to that achieved for R99 GSM/EGPRS terminals in GSM/EGPRS networks today, and ideally comparable with that of LTE. Optimisations for low-cost MTC UEs should minimise impact on the spectrum efficiency achievable for other terminals (normal LTE terminals) in LTE Release 8-10 networks.

- Ensure that service coverage footprint of low-cost MTC UE based on LTE is not any worse than the service coverage footprint of GSM/EGPRS MTC device (in an GSM/EGPRS network) or that of "normal LTE UEs" (in an LTE network) assuming on the same spectrum band.

- - Coverage improvement of 20dB should be targeted for low-cost MTC UEs in comparison to defined LTE cell coverage footprint as engineered for "normal LTE UEs.- Ensure that overall power consumption is no worse than existing GSM/GPRS based MTC devices.

- Ensure good radio frequency coexistence with legacy (Release 8-10) LTE radio interface and networks.

- Target operation of low-cost MTC UEs and legacy LTE UEs on the same carrier.

- Re-use the existing LTE/SAE network architecture.

- Solutions should be specified in terms of changes to the Rel 10 version of the specifications

- The study item shall consider optimizations for both FDD and TDD mode.

- The initial phase of the study shall focus on solutions that do not necessarily require changes to the LTE base station hardware.

- - Low-cost MTC device support limited mobility (i.e. no support of seamless handover; ability to operate in networks in different countries) and are low power consumption modules

5.2 Evaluation methodology

Based on the possibility that candidate solutions recommended as part of this study to allow cost reduction and coverage improvement may also bring a reduction in LTE system performance, methodology for both performance evaluation cost and coverage analysis is needed.

In order to achieve objective comparison of diverse analysis results for performance cost and coverage improvements from different companies, it is important to align the basic assumption for a reference LTE modem. The following is assumed:

- System bandwidth is 20MHz
- Category-1 LTE UE
- Single RAT
- Single band
- TDD/Full duplex FDD
- Direct DL and UL wide-area-network access from MTC devices to eNB

5.2.1 Methodology for performance evaluation

An evaluation methodology is provided for performance analysis of power consumption, coverage, and cell spectral efficiency.

5.2.1.1 Power consumption analysis

Power consumption is a function of many factors, such as active transmission time, transmit power level and PA efficiency, sleep mode duration, active reception time, receiver processing time/complexity. Some factors, like sleep mode duration, may depend on network configuration and traffic/signalling patterns, and some other factors, such as PA efficiency and receiver processing may be implementation specific.

Power consumption of the RF module can be estimated by:

- Reception time
- Transmission time and total UE transmit power during the transmitting time
- DC power consumption of Power Amplifier / PA efficiency

Power estimation for most baseband integrated circuits is usually implemented by commercial power estimation tools. In order to obtain the baseband power consumption conveniently, it is recommended to use the following method instead:

- Baseband complexity evaluation or comparison

5.2.1.2 Coverage analysis

A link budget is a reasonable method for coverage analysis. The following link budget tables capture the reference Maximum Coupling Loss (MCL) that can be used when comparing with that of a low-cost LTE MTC device, for example, to compare the MCL of MTC devices to the reference MCL in GSM/GPRS when assessing if service coverage provided to low-cost MTC UE is not worse than GSM/GPRS, or to compare the MCL of MTC devices to the reference MCL in LTE when assessing if the same defined LTE cell coverage footprint as engineered for "normal LTE UEs" can be ensured.

The values of some of the parameters of the link budget need to be common to all candidate solutions, and any solution-specific parameter values have to be determined by analysis or by simulation.

The link budget for GSM/EGPRS as benchmark should be assessed. Required SINR is from [3], 5dB Rx processing gain is considered, and 4 dB back off is assumed when 8PSK is involved. The Maximum Coupling Loss (MCL) calculations for GSM/EGPRS are presented in Table 5.2.1.2-1. The minimal MCL in Table 5.2.1.2-1 is minimal coverage requirement for low-cost UE.

Table 5.2.1.2-1: MCL calculation for GSM/EGPRS

Physical channel name	**UL**	**DL**
Data rate(kbps)	20 (1 TSL)	20 (2 TSL)
Transmitter		
(1) Tx power (dBm)	29	43
Receiver		
(2) Thermal noise density (dBm/Hz)	-174	-174
(3) Receiver noise figure (dB)	5	9
(4) Interference margin (dB)	0	0
(5) Occupied channel bandwidth (Hz)	180000	180000
(6) Effective noise power = (2) + (3) + (4) + 10 log((5)) (dBm)	-116.4	-112.4
(7) Required SINR (dB)	11	7
(8) Receiver sensitivity = (6) + (7) (dBm)	-105.4	-105.4
(9) Rx processing gain	5	0
(10) MCL = (1) –(8) + (9) (dB)	139.4	148.4

The MCL calculations for normal LTE FDD are given in Table 5.2.1.2-2. PHICH is neglected and the function of PHICH can be implemented by PDCCH in case of cell edge.

Table 5.2.1.2-2: MCL calculation for normal LTE FDD (see Note 1)

Physical channel name	PUCCH (1a)	PRACH	PUSCH	PDSCH	PBCH	SCH	PDCCH (1A)
Data rate(kbps)			20	20			
Transmitter							
Max Tx power (dBm)	23	23	23	46	46	46	46
(1) Actual Tx power (dBm)	23.0	23.0	23.0	32.0	36.8	36.8	42.8
Receiver							
(2) Thermal noise density (dBm/Hz)	-174	-174	-174	-174	-174	-174	-174
(3) Receiver noise figure (dB)	5	5	5	9	9	9	9
(4) Interference margin (dB)	0	0	0	0	0	0	0
(5) Occupied channel bandwidth (Hz)	180000	1080000	360000	360000	1080000	1080000	4320000
(6) Effective noise power = (2) + (3) + (4) + 10 log((5)) (dBm)	-116.4	-108.7	-113.4	-109.4	-104.7	-104.7	-98.6
(7) Required SINR (dB)	-7.8	-10.0	-4.3	-4.0	-7.5	-7.8	-4.7
(8) Receiver sensitivity = (6) + (7) (dBm)	-124.24	-118.7	-117.7	-113.4	-112.2	-112.5	-103.34
(9) MCL = (1) – (8) (dB)	147.2	141.7	140.7	145.4	149.0	149.3	146.1
NOTE 1: eNB is assumed with 2 Tx and 2 Rx in FDD systems.							

The MCL calculations for normal LTE TDD are summarized in Table 5.2.1.2-3.

Table 5.2.1.2-3: MCL calculation for normal LTE TDD (see Note 2)

Physical channel name	PUCCH (1a)	PRACH	PUSCH	PDSCH	PBCH	SCH	PDCCH (1A)
Data rate(kbps)			20	20			
Transmitter							
(0) Max Tx power (dBm)	23	23	23	49	49	49	49
(1) Actual Tx power (dBm)	23.0	23.0	23.0	32.0	36.8	36.8	42.8
Receiver							
(2) Thermal noise density (dBm/Hz)	-174	-174	-174	-174	-174	-174	-174
(3) Receiver noise figure (dB)	5	5	5	9	9	9	9
(4) Interference margin (dB)	0	0	0	0	0	0	0
(5) Occupied channel bandwidth (Hz)	180000	1080000	360000	360000	1080000	1080000	4320000
(6) Effective noise power = (2) + (3) + (4) + 10 log((5)) (dBm)	-116.4	-108.7	-113.4	-109.4	-104.7	-104.7	-98.6
(7) Required SINR (dB)	-10	-15	-11.0	-6.7	-7.5	-7.8	-5.5
(8) Receiver sensitivity = (6) + (7) (dBm)	-126.4	-123.7	-124.4	-116.1	-112.2	-112.5	-104.1
(9) MCL = (1) – (8) (dB)	149.4	146.7	147.4	148.1	149.0	149.3	146.9
NOTE 2: eNB is assumed with 8 Tx and 8 Rx in TDD systems							

.

The transmission mode for LTE FDD and TDD downlink channel is Transmission Mode 2. UE is assumed with 1 Tx and 2 Rx in both FDD and TDD systems. 1 OFDM symbol is used for PDCCH. The required SINRs of PDSCH and PUSCH for both FDD and TDD systems are obtained by simulation. The required SINRs of control channels for FDD in Table 5.2.1.2-2 are averages from all the sourcing companies in [4] excluding source 10. The required SINRs of control channels for TDD in Table 5.2.1.2-3 are from source 10 in [4]. For remaining parameters, refer to [4].

5.2.1.3 Cell spectral efficiency

Two approaches can be used to compute the average spectral efficiency:

(1) Cell spectral efficiency is determined through system simulation.

(2) Relative spectral efficiency reduction to Rel -8-10 LTE or increase to R99 GSM/EGPRS is determined analytically.

The reference spectral efficiency of GSM/EGPRS is 0.3bit/s/Hz/site for downlink and 0.1bit/s/Hz/site for uplink.

The reference spectral efficiency of LTE FDD is 1.5 bit/s/Hz/site for downlink and 1.2 bit/s/Hz/site for uplink and the reference spectral efficiency of LTE TDD is 2.0 bit/s/Hz/site for downlink and 1.7 bit/s/Hz/site for uplink, based on the system simulation under the following assumptions:

1) Simulation scenario is 3GPP case1.

2) Full duplex FDD @ 900MHz. Half duplex TDD @ 2.6GHz

3) 10MHz system bandwidth.

4) UEs are uniformly distributed with average 10 UEs per sector.

5) Traffic model is full buffer.

6) Channel model is SCM.

7) Scheduling algorithm is PF (Proportional Fairness).

8) FDD DL: 2 Tx, 2 Rx (Transmission Mode 6). UL: 1 Tx, 2 Rx.

9) TDD: DL: 8 Tx, 2 Rx (Transmission Mode 7). UL: 1 Tx, 8 Rx

Other informative parameters for simulation are summarized in Table 5.2.1.3.

Table 5.2.1.3: Parameters for simulation

Parameters	Assumptions
Duplex method and bandwidths	TDD: configuration 1: DL:SP:UL = 2:1:2 Special subframe: DwPTS 11 symbol, GP 1 symbol, UpPTS 2 symbol
UE speed	3km/h
Uplink transmission scheme	LTE Rel-8 SIMO
Downlink HARQ scheme	HARQ-CC
Link adaptation	CQI/SRS: 5ms delay 10ms period; FDD: PUCCH 1-1; TDD: PUCCH 2-0
Antenna configuration at Base Station	Correlated cross-polarized antenna
Antenna configuration at UE	Vertically-polarized, with 0.5 lambda spacing
Overhead assumption	DL overhead: 3 OFDM symbols for DL CCHs, 2 port CRS for TM6, and 1 port CRS and 1 port DMRS for TM7.
Propagation model	L=I + 37.6log10(R), R in kilometers I=130.5--2.6GHz, I=120.9--900MHz.

The cell spectrum efficiency is expected to have a range that depends on the ratio of MTC and non-MTC devices, ranging from at least that achieved by R99 GSM/EGPRS to that achieved by Rel-10 LTE. Note that the reference spectral efficiencies assume no MTC devices. Potential cost reduction techniques captured in the TR that will have any impact to spectral efficiency should present spectrum efficiency as well as cost analysis. The average spectral efficiency for MTC and non-MTC UEs can be computed separately, so as to capture the different impact on MTC and non-MTC UEs.

5.2.2 Methodology for cost analysis

The cost drivers are broadly categorized into two parts, RF components and processing, which may need different analysis methodology. The ADC/DAC and L2/L3 protocol support are included within the processing category. The cost analysis methodology should identify the percentage cost of each of the two parts, and, for each cost reduction technique, the relative percentage cost reduction to that of the reference LTE modem.

5.2.2.1 Baseband cost/complexity analysis

Baseband cost can be represented to some extent by the required baseband operations. In addition, resource occupied on chip can also be considered. A baseband cost/complexity metric relevant to the analyzed cost reduction technique should be used. It should be noted that the impact of complexity reduction on cost and/or performance is dependent on various factors including implementation.

Examples of possible metrics include:

(1) Complexity (in absolute or relative terms)

Although the complexity of the baseband module is implementation dependent, it can be estimated according to

- Elapsed time
- Number of LLR values
- Number of baseband signal operations/sec
- Number of higher layer radio protocol processing operations/sec
- Number of basic baseband operations per information bit

(2) Resource occupied on chip (in absolute or relative terms)

- Buffer size
- Number of ASIC/FPGA gates

5.2.2.2 RF cost analysis

Under the basic assumption for LTE modem, it is recommended to use the following RF cost metric:

- Number of RF chains/antenna ports
- Replacing of some components by less expensive components
    - Replacing duplexer with switch
    - Removing PA

Instead of an absolute cost in terms of number of components, the cost can be expressed as a relative cost compared to the reference LTE modem.

5.3 Cost drivers of reference LTE modem

The table below reflects the current cost structure of a reference category 1 LTE UE modem implemented with the current state of the art and the cost may evolve over time. Components such as I/O and processors are excluded in below.

Table 5.3.1: Fractional cost breakdown relative to RF and Baseband functions for reference LTE UE modem

Functional block	**Source 1**	**Source 2**	**Source 3**	**Source 4**	**Source 5**	**Source 6**	**Source 7**	**Source 8**	**Source 9**	**Recommended (for Evaluation)**
Duplex mode	FDD	FDD	FDD	FDD	TDD	FDD	FDD	FDD	FDD	
Frequency Band assumed	Sub GHz	2 Sub GHz	2 GHz	Sub GHz	2 GHz	Sub GHz	Sub GHz	Sub GHz	Sub GHz	
Ratio of RF to baseband cost	40:60	40:60	40:60	40:60	40:60	40:60	50:50	30:70	40:60	40:60
	RF									
Power amplifier	25%	25%	30%	25-30%	25-30%	10-15%	15%	25%	~25%	25%-30%
Filters	10%	10%	10%	5-10%	5-10%	(included in RF transceiver)	10%	10%	(included in RF transceiver)	5%-10%
RF transceiver (including LNAs, mixer, and local oscillator)	40%	45%	35%	~50%	50%-55%	50% (Includes Filter)	40%	45%	~50%	40%-50%
Duplexer / Switch	25%	20%	25%	15-20%	15% (switch)	30%	15%	20%	~20%	15%-25%
Other	~0%	~0%	0%	NA	NA	5-10%	20% (Cost for 2 antennas)	0%	~0%	0%-10%
Total	100%	100%	100%	95%~110	95%-110%	95-105%	100%	100%	~95%	95%-110%

Functional block	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7	Source 8	Source 9	Recommended (for Evaluation)
	Baseband									
ADC / DAC	10%	~10%	10%	15-20% (Includes digital front-end)	10% (Includes digital front-end)	NA	15%	10%	10%	10%
FFT/IFFT	5%	~5%	10%	~5%	~5%	NA	5%	5%	5-10%	5%
Post-FFT data buffering	15%	~10%	10%	10-15%	15%	NA	10%	10%	NA (included in RX processing block)	10%-15%
Receiver processing block	35%	~25% (Including CSI measurement and channel estimation)	30% (Includes "MIMO specific processing")	~20% (Includes "MIMO specific processing")	~20% (Includes "MIMO specific processing")	40-45% (includes subframe buffering)	20%	35% (includes subframe buffering and MIMO specific processing)	40% (include subframe buffering, Include MIMO specific processing)	20%-35%
Turbo decoding	5%	10%~15% (Including turbo decoding and demodulation)	10%	~10% (LLR computation is part of Rx processing)	10%~15%	NA	10%	5%	5%~10%	5%-15%
HARQ buffer	15%	~10%	10%	~10%	15%	10%	10%	15%	15%	10%-15%
DL control processing & decoder	5%	5%~10% (Including convolution decoding and demodulation)	5%	~5%	5%	NA	5%	5%	~5%	5%
Synchronization / cell search block	10%	~10%	10%	10-15%	10-15%	10-15%	10%	10%	~10%	10%-15%
UL processing block	<5%	~10%	10%	~5%	<5%	NA	10%	5%	10%	5%-10%
MIMO specific processing blocks	<5%	~5%	0%	NA	NA	10-15%	5%	0%	NA	5%-15%
Other	~0%	NA	0%	~10%	NA	20-25% (includes ADC/DAC, FFT/IFFT, etc.)	NA	0%	NA	0%
Total	100-110%	100~110%	105%	100%~115%	95%-105%	90-110%	100%	100%	100-110%	90%-110%

6 Concepts for provisioning of low-cost MTC UE and cost analysis

6.1 Introduction

Clause 6 describes concepts for provisioning of low-cost MTC UEs and cost analysis. The baseline for cost analysis is a single-band, single RAT, 20MHz bandwidth Category 1 UE [2]. Concepts that may provide significant cost savings include:

- Reduction of maximum bandwidth
- Single receive RF chain
- Reduction of peak rate
- Reduction of transmit power
- Half duplex operation
- Reduction of supported downlink transmission modes

6.2 Reduction of maximum bandwidth

6.2.1 Description

The maximum bandwidth supported by normal LTE UEs is 20MHz. One potential technique to reduce the UE cost is to reduce the maximum bandwidth that the UE supports from 20MHz to a lower bandwidth (e.g., 1.4MHz, 3MHz or 5MHz). The reduction of the maximum bandwidth can be applied to the downlink and/or uplink, the RF and/or baseband components, the data and/or control channels. To be more specific, the following options have been considered and evaluated, which allow the bandwidth reduction on the DL and UL to be considered separately.

- DL
    - Option DL-1: Reduced bandwidth for both RF and baseband
    - Option DL-2: Reduced bandwidth for baseband only for both data channel and control channels
    - Option DL-3: Reduced bandwidth for data channel in baseband only, while the control channels are still allowed to use the carrier bandwidth
- UL
    - Option UL-1: Reduced bandwidth for both RF and baseband
    - Option UL-2: No bandwidth reduction
        - This option does not have any impact on coverage, power consumption, specifications, performance, and UE cost.

For all these options, the reduced bandwidth is assumed to be no less than 1.4MHz, and the frequency location of the reduced bandwidth is assumed to be fixed at the center of the carrier bandwidth. Technically, any combination of the DL and UL options is possible. However, some of the combinations may make more practical sense. For example, DL-2 would be a more natural choice than DL-1 when combined with UL-2.

Note that this is not intended to be an exhaustive list of the possible options. Some interesting variations of these options could allow the frequency location of the reduced bandwidth to be changed semi-statically, dynamically, or in a pre-defined pattern for each UE. Some of these variations could potentially allow more MTC UEs to be supported in the system. Taking the extension of DL-3 as an example,

- If the frequency location of the data channel is semi-statically configured, it is expected to provide the same cost saving as DL-3, with some additional specification impact.
- If the frequency location of the data channel is dynamically changed using grants, it would be the same as one of the techniques for reduced peak rate, restricting the number of PRBs, as discussed in subclause 6.4.

Nonetheless, the discussion in this subclause is restricted to the options listed above.

With reduced bandwidth, the cost of RF and baseband components can potentially be reduced. Depending on which option is assumed, the relative cost savings and the specification impact can be different.

6.2.2 Analysis/evaluation of performance against requirements

6.2.2.1 Coverage analysis

Reduction of maximum bandwidth results in some degradation in the coverage for the MTC UEs compared to normal LTE UEs.

For the DL,

- PDSCH: for all three options, the coverage of PDSCH can be affected due to the loss in frequency selective scheduling gain.
- DL control channels (PCFICH/PHICH/PDCCH):
  - For option DL-1 and DL-2, the performance of PCFICH/PHICH/PDCCH is expected to degrade due to the loss in frequency diversity, thus possibly reducing the coverage for these channels. Whether the coverage would degrade, or the extent of the degradation would depend on what solution is adopted for PCFICH/PHICH/PDCCH in the reduced bandwidth. Some enhancements can be considered for the new PCFICH/PHICH/PDCCH design to improve the coverage.
  - For option DL-3, PCFICH/PHICH/PDCCH are still transmitted across the carrier bandwidth, thus no loss in frequency diversity. If CRS is processed in the entire carrier bandwidth, as is currently done, the performance of PCFICH/PHICH/PDCCH should remain the same. However, the coverage may be affected if CRS is processed within narrower bandwidth in PDSCH region which results in larger channel estimation error.

For the UL (option UL-1 only),

- The coverage of PUCCH is smaller due to the loss in frequency diversity.
- The coverage of PUSCH can be smaller due to the loss in frequency hopping gain or frequency selective scheduling gain.
- The coverage of PRACH is not impacted.

The coverage analysis in subclause 5.2.1.2 shows that the normal LTE system is UL limited. With the degradation resulting from reduced maximum bandwidth, the coverage is still likely to be UL limited and likely remains better than or similar as GSM/EGPRS systems.

6.2.2.2 Minimum data rate

Bandwidth reduction has no impact on the minimum data rate, in the sense that the required data rates (118.4kbps downlink and 59.2kbps uplink) can still be supported with the reduced bandwidth. Note that this assumes the reduced bandwidth is no less than 1.4MHz.

6.2.2.3 Power consumption

Reducing the maximum bandwidth provides a reduction in power consumption due to the lower baseband processing requirements in some of the components, possibly including ADC/DAC, FFT, buffering and DL/UL processing blocks. Exactly which components are affected depends on the options being chosen.

However, the reception time may become larger if the performance degradation on PDSCH results in a longer transmission time, thus possibly increasing the power consumption.

Moreover, for option UL-1, if there is performance degradation on PUCCH/PUSCH, the UE transmit power may become higher compared to normal LTE UEs, or the transmission time may become longer due to a lower instantaneous data rate. This would increase the power consumption.

6.2.2.4 Impact on specification

One potential solution to avoid any specification impact is to introduce a low bandwidth carrier (same as the bandwidth supported by MTC UEs), and all MTC UEs are served by this carrier. Carrier aggregation can be used for non-MTC UEs to utilize the bandwidth associated with the other carrier(s). The main disadvantages of this solution include:

- Inefficient use of the spectrum if there is guard band between carriers. New carrier type may be able to improve the efficiency if it is defined in a way that the guard band is not needed, but it may not be accessible to Rel-8/9/10 UEs.
- If the eNB and/or the non-MTC UEs do not support carrier aggregation, there can be UE and system performance degradation due to less bandwidth per carrier and loss of trunking efficiency.

To support the MTC UEs with reduced bandwidth in a carrier with larger bandwidth, some specification changes may be expected. Further optimization of the solutions to reduce the impact to system performance, if performed, may require additional changes to specifications.

- DL bandwidth reduction
    - For all three options, specifications for PSS/SSS and PBCH are not expected to be impacted, because they are always transmitted in the innermost 1.08 MHz bandwidth.
    - For all three options, specifications for SIB and paging are not expected to be impacted, because the eNB can schedule them within the reduced bandwidth. However, specifications may be impacted if any necessary change is identified in the future or further optimization is to be done.
    - For all three options, PDSCH specifications are not expected to be impacted, because the eNB can schedule them within the reduced bandwidth.
    - For option DL-1 and option DL-2, new designs for PCFICH/PHICH/PDCCH are needed. These channels would need to be sent within the bandwidth supported by the MTC UEs, and a common search space would also need to be defined. The corresponding PUCCH resource mapping for HARQ-ACK may also be affected. The specification impact is expected to be significant. Note that some of these aspects may be covered by the Enhanced DL control channel(s) work item [7].
- UL bandwidth reduction (option UL-1 only)
    - For PUCCH, there is no strict need for specification change. The eNB could configure PUCCH to be located within the reduced bandwidth. However, it results in a few segments of frequency resources for PUSCH, separated by the PRBs used for PUCCH. Given that PUSCH for each UE has SC-FDMA transmission and needs to be allocated contiguous frequency resources, this may cause some performance degradation for non-MTC UEs.
    - Specifications on SRS is not expected to be impacted, although implementation changes may be needed to handle the co-existence of SRS for the MTC and non-MTC UEs.
- Random access procedure
    - This includes the preamble transmission on PRACH, Message 3 transmission on PUSCH, Message 2/4 transmissions on PDSCH, and the corresponding signalling (e.g. grants, HARQ-ACK).
    - It may be possible to use an implementation solution to make the system work without specification change.
        - Without any specification change, the eNB cannot differentiate the MTC and non-MTC UEs, all UEs are handled in the same manner.
        - When option UL-1 is used, the eNB could configure PRACH to fall within the reduced bandwidth, and the subsequent Message 3 for all UEs could be scheduled within the reduced bandwidth.
        - Message 2/4 transmissions on PDSCH for all UEs could be scheduled within the reduced

    bandwidth for all three DL options. Further, for option DL-1 and DL-2, the grants for Message 2/4 and HARQ-ACK for Message 3 on PHICH for all UEs would need to be duplicated to ensure that they can be received by both MTC and non-MTC UEs.

    - When some of these messages are transmitted within the reduced bandwidth for all UEs, plus the possible duplication of the corresponding DL signalling, there may be some performance and capacity limitations that apply to both MTC and non-MTC UEs.

- o Some specification changes may be introduced to alleviate the performance and capacity limitations.

    - One possibility is to change PRACH so that the eNB can differentiate MTC and non-MTC UEs. In this case, the eNB can process the random access separately for MTC and non-MTC UEs.

In summary, minimal specification impact is expected from the combination of option DL-3 and UL-2. When option DL-3 is not used, the most significant impact is expected from the downlink control channels, while all the other channels/signals may be handled by implementation, with possible performance degradation. However, if the performance degradation is considered as so significant that further optimization is needed to improve the performance, more specification impact would be expected.

6.2.2.5 Cell spectral efficiency

For all three options for the DL, there may be some degradation in the DL cell spectral efficiency due to the loss in frequency selective scheduling gain. When the degradation exists, it is expected to be moderate. For example, one sourcing company showed that the DL spectral efficiency degrades by about 10% when the bandwidth is reduced from 20 MHz to 3 MHz.

For option UL-1, there can be some degradation in the UL cell spectral efficiency due to the loss in frequency selective scheduling gain or PUSCH frequency hopping gain.

Note that mostly only the spectral efficiency for the MTC UEs is impacted, while the spectral efficiency for the non-MTC UEs remains unaffected, or is minimally affected (e.g. the frequency fragmentation caused by PUCCH for option UL-2). Moreover, the reduced spectral efficiency is still much higher than that of GSM/EGPRS.

By reducing the maximum bandwidth, the MTC UEs can only be served within that bandwidth, thus limiting the capacity in terms of the number of MTC UEs that can be supported. Generally speaking, for the options discussed, the capacity for MTC UEs scales linearly with the maximum bandwidth supported by the MTC UEs. However, if the frequency location of different MTC UEs can be configured differently (for which the impact is not explicitly discussed in this subclause), no significant impact is expected on the capacity for MTC UEs. It is important to take into account the capacity and the system scalability as more MTC UEs are deployed in the future.

6.2.3 Analysis/evaluation of cost reduction

The estimated cost savings provided by the sourcing companies are summarized in Table 6.2.3-1. Different bandwidths were evaluated, including 1.4, 3 and 5 MHz. The options for DL and UL bandwidth reduction are also specified in the table. The average cost saving of each DL option is summarized in Table 6.2.3-2, using the recommended cost breakdown ranges and the company provided discount values with regard to the components related to RF and baseband cost saving for 1.4MHz reduced bandwidth from Table 6.2.3-1. Option DL-1 provides larger cost savings than option DL-2, and option DL-2 provides larger cost savings than option DL-3.

The reference Category 1 UE supports the peak rate of 10 Mbps on the DL and 5 Mbps on the UL. When the bandwidth is reduced to 1.4 MHz for MTC UEs, it can no longer reach the peak rate supported by Category 1 UE. Therefore, for the cost analysis for 1.4 MHz, the corresponding peak rate reduction is also taken into account. In this case, the peak rate becomes ~4.4 Mbps on the DL and ~2.3 Mbps on the UL. However, when the reduced bandwidth is 3 MHz or higher, the peak rate remains the same as Category 1 UEs, which means there is no cost savings associated with the reduced peak rate.

Table 6.2.3-1 Relative cost saving estimation for the reduction of maximum bandwidth

Functional block (Ratio of RF to baseband cost 40:60)	Recommended cost breakdown (for Evaluation)	Source 1				Source 2	Source 3	Source 4			Source 5	Source 6			Source 7
Reduced bandwidth (MHz)		1.4	1.4	1.4	1.4	1.4 / 5	1.4	1.4	1.4	1.4	3	1.4	1.4	1.4	5
Option		DL-1	DL-2	DL-3	UL-1	DL-1 UL-1	DL-1 UL-1	DL-1 UL-1	DL-2 UL-2	DL-3 UL-2	DL-1 UL-1	DL-1 UL-1	DL-2 UL-1	DL-3 UL-1	DL-1 UL-1
RF															
Power amplifier	25%-30%	NA	NA	NA	25%	NA	NA	NA	NA	NA	20%	NA	NA	NA	
Filters	5%-10%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
RF transceiver (including LNAs, mixer, and local oscillator)	40%-50%	20%	NA	NA	NA	NA	NA	NA	NA	NA	30%	NA	NA	NA	
Duplexer /Switch	15%-25%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Other	0%-10%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Total of RF	95%-110%	9%	0%	0%	7%	0%	0%	0%	0%	0%	17%	0%	0%	0%	
Baseband															
ADC / DAC	10%	40%	NA	NA	10%		93%	94%	NA	NA	NA	93%	NA	NA	
FFT/IFFT	5%	93%	93%	NA	NA		96%	96%	NA	NA	80%	96%	NA	NA	
Post-FFT data buffering	10%-15%	93%	93%	0%	NA		93%	94%	94%	74%	NA	93%	93%	73%	
Receiver processing block	20%-35%	70%	70%	35%	NA		93%	~50%	~50%	~50%	50%	~93%	~93%	~50%	
Turbo decoding	5%-15%	57%	57%	57%	NA		56%	~50%	~50%	~50%	NA	56%	56%	56%	
HARQ buffer	10%-15%	57%	57%	57%	NA		56%	94%	94%	94%	NA	56%	56%	56%	
DL control processing & decoder	5%	70%	70%	NA	NA		50%	NA	NA	NA	NA	~50%	~50%	NA	
Synchronization / cell search block	10%-15%	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	
UL processing block	5%-10%	NA	NA	NA	50%		54%	NA	NA	NA	NA	54%	54%	54%	
MIMO specific processing blocks	5%-15%	NA	NA	NA	NA		93%	NA	NA	NA	NA	NA	NA	NA	
Other	0%	NA	NA	NA	NA			NA	NA	NA	NA	NA	NA	NA	
Total of Baseband	90%-110%	56%	52%	22.5%	4.7%	77% / 38%	70-80%	55%	38%	35%	23%	69%	55%	40%	
Overall relative cost savings		**37.2%**	**31.2%**	**13.5%**	**5.6%**	**46% / 23%**	**40-50%**	**33%**	**23%**	**21%**	**20%**	**41%**	**33%**	**24%**	**6-10% (Note)**

NOTE: The analysis by this source was based on estimated component cost and not computational or memory reduction.

Table 6.2.3-2: Summary of average cost saving for each DL bandwidth reduction option

Option Average cost saving	DL-1	DL-2	DL-3
Mean	~39%	~28%	~19%

The observations from these evaluation results provided in the Table 6.2.3-1 and Table 6.2.3-2 are summarized as follows:

- Reduction of maximum bandwidth provides significant cost savings, although the exact number for the relative cost savings varies from one source to another. The cost savings are mainly due to reduced baseband processing.

- Reduction of maximum bandwidth even without lowering peak data rate (e.g. reduced bandwidth of 3 or 5 MHz) provides considerable cost savings mainly from lower complexity of FFT/IFFT and receiver processing block of baseband processing.

- Reduced bandwidth on the UL provides very small savings in the overall UE cost, because the RF component cost is not sensitive to the bandwidth, and the cost of the UL processing block is only a small portion of the total baseband cost. The cost savings come from the UL processing block, and possibly power amplifier and ADC/DAC, which is estimated to be about 5% or less of the total UE cost.

- Reduction of maximum bandwidth provides minimal or small savings for the RF components.

6.3 Single receive RF chain

6.3.1 Description

Removing the requirement for an MTC UE to possess two antennas and two receive RF chains is expected to provide cost saving. The cost saving of using a single receive RF chain will be achieved in both RF and baseband processing aspects of the UE; however there would be an associated loss in downlink coverage and spectral efficiency due to degradation in MTC UE receiver performance.

6.3.2 Analysis/evaluation of performance against requirements

6.3.2.1 Coverage analysis

The requirements in subclause 5.1 state that the coverage for MTC UEs must be at least comparable to that of GSM/EGPRS and legacy LTE. Use of a single receive RF chain would have an impact on the downlink coverage for MTC UEs. It may be possible to compensate for these impacts through implementation choices or specification changes.

Whether the use of a single receive RF chain would make an LTE network downlink limited depends on the configuration of the Release 10 network. Many LTE networks are uplink-limited for the case of legacy dual receive RF chain UEs, hence some loss of downlink coverage may not lead to an overall system coverage loss in such networks.

A reduced SINR for PSS/SSS/PBCH for a single receive RF chain UE primarily translates into a penalty in terms of acquisition time. However decoding of PCFICH/PHICH/PDCCH is undertaken by the UE in a single subframe only and there will be a coverage penalty when a single receive RF chain is used. Depending on the channel conditions, the performance loss is expected to be of the order of 3-6dB for PDCCH (for 1% BLER), 3-5dB for PCFICH (for 1% BLER) and 3-6dB for PHICH (for 0.1% BLER). It is observed that uplink coverage or PDCCH may be limited for FDD and PDCCH may be limited for TDD.

Without solutions to compensate for the degradation of receiver performance, MTC UEs with a single receive RF chain may not achieve the same coverage as legacy dual receive RF chain UEs. However it is recognised that the coverage of single receive RF chain UEs exceeds that of GSM/EGPRS UEs.

6.3.2.2 Power consumption

Power consumption savings are achieved in the RF module as a result of only a single receive RF chain being used; power consumption is reduced in the baseband due to the corresponding reduction in baseband complexity. However, a single receive RF chain would result in a longer acquisition time to obtain the PSS/SSS/PBCH with an associated increase in RRC_IDLE state average power consumption. Reduced downlink spectral efficiency would require larger coded blocks or a longer reception time for the PDSCH to deliver the same amount of data. This would increase the average power consumption.

6.3.2.3 Impact on specification

TSG RAN WG4 specifications assume a dual receive RF chain UE implementation, therefore a single receive RF chain UE will require additional work in TSG RAN WG4 to define corresponding receiver characteristics, performance requirements and requirements relating to the reporting of channel state information. This work may consider the implications of a dual receive RF chain UE's antenna gain imbalance not being applicable to the case of single receive RF chain UEs. Impacts on TSG RAN WG4 specifications are in any case expected to extend beyond REFSENS requirements, likely encompassing many receiver requirements.

The coverage of a single receive RF chain UE implementation may, depending on channel conditions, be limited by the PDCCH. To compensate for downlink coverage loss, TSG RAN WG1 specification changes may need to be introduced to support a single receive RF chain UE implementation. Compensation for downlink coverage loss may also be achieved by implementation. Standards impacting schemes to compensate for PDCCH downlink coverage include, but are not limited to, the following: definition of higher aggregation levels for PDCCH, compact DCI formats and the use of ePDCCH developed in the Enhanced DL control channel(s) work item [7].

The random access procedure can possibly rely on implementation to support UEs with a single receive RF chain. This would require the eNB to always use a format for Message 2/4 that can be successfully decoded by the UEs with a single receive RF chain. Alternatively, specification changes can be introduced so that on reception of a PRACH the eNB knows whether the UE has a single receive RF chain before sending Message 2/4. If the eNB is aware that the UE has a single receive RF chain, then account can be taken when choosing a format for Message 2/4.

6.3.2.4 Cell spectral efficiency

Spectral efficiency reduction when considering a single (rather than dual) receive RF chain is expected to be due to a number of factors including, but not limited to, the following:

- Use of more robust (but less efficient) MCS on PDSCH.
- PDCCH limitations limiting the number of UEs that can be scheduled in the downlink resulting from, for example, the use of higher aggregation levels for the case of single receive RF chain UEs experiencing a reduced received SINR.
- Restriction in the ability to implement advanced receiver algorithms with spatial interference rejection capabilities.

The estimated spectral efficiency reduction provided by the sourcing companies when considering a single (rather than dual) receive RF chain is summarized in Table 6.3.2.4.1 for FDD and Table 6.3.2.4.2 for TDD. Simulation parameters are described in sublause 5.2.1.3.

Table 6.3.2.4-1 FDD spectral efficiency reduction estimation for a single receive RF chain

Source	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7
Spectral Efficiency reduction	26%	21%	16%	18-26%	34%	27%	25%

Table 6.3.2.4-2 TDD spectral efficiency reduction estimation for a single receive RF chain

Source	Source 1	Source 2
Spectral Efficiency reduction	14%	20%

6.3.3 Analysis/evaluation of cost reduction

When the number of receive RF chains is reduced from two (for the reference LTE modem) to one, the costs of the following RF aspects are reduced:

- The receive filtering cost can be reduced by approximately 50% relative to that of the reference LTE modem when the number of receive RF chains is reduced by a factor of 2.

- The cost of the receive RF chains can be reduced by up to 50% relative to that of the reference LTE modem. However, since the transmitter and common parts for, e.g., frequency synthesis cannot be removed, the cost reduction of the whole RF transceiver will be considerably less.

- The cost of the duplexer itself is not reduced since the duplexer only exists on the antenna that is driven by the UE transmitter. However the receive branch that is removed would contain a filter in place of the duplexer and this filter could be eliminated for a single receive RF chain UE. Since the cost of this filter is typically less than the cost of the duplexer, the overall duplexing cost can be considered to be slightly reduced compared to the reference LTE modem's duplexing cost.

The use of a single receive RF chain also reduces the cost of the following baseband processing functional blocks:

- In the downlink, the FFT is only required on the samples received on the single receive RF chain. Hence the number of FFT operations is reduced by a factor of 2. There is no change to the IFFT requirements in the uplink from the support of a single receive RF chain. Hence the FFT/IFFT cost for a single receive RF chain MTC UE is estimated to be reduced relative to that of the reference LTE modem.

- Separate channel estimates are required for each receive RF chain. When the number of receive RF chains is reduced from two to a single receive RF chain, the channel estimator cost can be reduced by approximately 50% relative to that of the reference LTE modem.

- Only a single ADC is required to operate on the single receive RF chain, hence the ADC cost may be reduced by approximately 50% relative to that of the reference LTE modem. The cost reduced MTC UE would still contain a single transmitter RF chain, hence DAC cost is unlikely to be reduced. Given that the ADC functional block is typically more costly than the DAC functional block, the overall ADC / DAC cost could be reduced compared to that of the reference LTE modem.

- The UE only needs to store samples from the single receive RF chain; hence the size of the post-FFT data buffer memory can be reduced by 50% relative to that of the reference LTE modem.

- The synchronisation and cell search blocks typically operate on samples from both receive RF chains, hence reducing the number of receive RF chains by a factor of 2 would typically reduce the cost of these functions by up to 50% relative to that of the reference LTE modem.

The estimated cost savings provided by the sourcing companies are summarized in Table 6.3.3.1. It is noted that the cost impact on UEs from potential techniques aimed at reducing the downlink coverage loss are not considered in this analysis.

Table 6.3.3.1 Relative cost saving estimation for a single receive RF chain

Functional block (Ratio of RF to baseband cost 40:60)	**Recommended cost breakdown** (for Evaluation)	**Source 1**	**Source 2**	**Source 3**	**Source 4**	**Source 5**	**Source 6**	**Source 7**	**Source 8**	**Source 9**
RF										
Power amplifier	25%-30%	NA		NA	NA	NA	NA			NA
Filters	5%-10%	50%		50%	50%	NA	50%			50%
RF transceiver **(including LNAs, mixer, and local oscillator)**	40%-50%	30%		50%	50%	30%	50%			20%
Duplexer /Switch	15%-25%	NA		NA	25%	NA	NA			25%
Other	0%-10%	NA		NA	NA	NA	NA			NA
Total of RF	***95%-110%***	***19%***	***15%***	***22.5%-30%***	***33%***	***12%***	***28%***	***20%***	***30%***	***14-21%***
Baseband										
ADC / DAC	10%	40%		30%	40%	40%	50%			30%
FFT/IFFT	5%	50%		NA	33%	50% (*only with FFT*)	50%			30%
Post-FFT data buffering	10%-15%	50%		50%	50%	NA	50%			50%
Receiver processing block	20%-35%	50%		50%	50%	50%	~40%			30%
Turbo decoding	5%-15%	NA		NA	NA	NA	NA			NA
HARQ buffer	10%-15%	NA		NA	NA	NA	NA			NA
DL control processing & decoder	5%	NA		NA	NA	NA	NA			20%
Synchronization / cell search block	10%-15%	50%		50%	50%	50%	NA			40%
UL processing block	5%-10%	NA		NA	NA	NA	NA			NA
MIMO specific processing blocks	5%-15%	NA		50%	100%	NA	NA			50%
Other	0%	NA		NA	NA	NA	NA			NA
Total of Baseband	***90%-110%***	***29%***	***12.5%***	***26-43%***	***33%***	***30%***	***25%***	***20-40%***	***44%***	***23-37%***
Overall relative cost savings		**25%**	**15%**	**25-38%**	**33%**	**23%**	**26%**	**20-32%**	**38%**	**19-31%**

Overall the estimated cost savings for a single receive RF chain MTC UE relative to that of the reference LTE modem is in the range 15-38%.

6.4 Reduction of peak rate

6.4.1 Description

The reference LTE modem is a Category 1 UE supporting 10296 transport block (TB) bits within a TTI on the downlink and 5160 bits on the uplink, where the number of transport block bits are influenced in part by characteristics of the UE category such as support of only single layer transmission on the downlink or no 64QAM support on the uplink [2]. There are various techniques that reduce the peak rate relative to the Category 1 UE and thereby provide a cost reduction. Though each technique could result in a new UE category with a smaller supported TB size and the associated characteristics, it is anticipated that one new lower UE category will be sufficient.

Techniques for peak rate reduction include:

1. Reduction of maximum transport block sizes for DL and UL
2. Restricting the number of PRBs in an assignment/grant
3. Restricting the maximum modulation order

The cost reductions of these techniques are not necessarily cumulative.

NOTE: Reduction of maximum bandwidth (refer to subclause 6.2) is also an option to reduce the peak rate.

6.4.2 Analysis/evaluation of performance against requirements

6.4.2.1 Coverage analysis

Reducing the peak rate in general does not make the coverage worse.

6.4.2.2 Minimum data rate

Reducing the peak rate has no impact on the minimum data rate as long as the TB size determined from the TB size table [5] exceeds the required minimum data rates (118.4kbps downlink and 59.2kbps uplink). Any TB restriction from a new lower UE category should also consider the characteristics of MTC traffic in annex A.

6.4.2.3 Power consumption

Reducing the peak rate in general does not make the power consumption worse, unless the TB size is restricted to such a degree that typical MTC traffic requires a larger number of TTI for transmission or reception.

The reduced complexity in processing a smaller maximum TB will typically reduce power consumption, as seen in turbo decoding and UL processing block. Restricting the maximum modulation order may reduce the ADC power consumption.

6.4.2.4 Impact on specification

The impact on the specification varies with each technique to reduce the peak rate. In all cases, a new entry to [2] is required and any characteristics of the restriction should be noted. Various tables in [5] may have entries that the new category UE will not use, and some DCI messages may have parameters values that will not be assigned; optimization of these tables and messages is not required, but is also not precluded.

6.4.2.5 Cell spectral efficiency

Reducing the peak rate in general does not degrade the cell spectral efficiency, as long as the maximum modulation order is not restricted. Restricting the maximum modulation order reduces the DL and the UL spectral efficiency. For example, if restricted to QPSK for both DL and UL, the spectral efficiency for FDD is reduced from 1.5 to 0.716 bit/s/Hz for DL and from 1.2 to 0.673 bit/s/Hz for UL. If restricted to QPSK for DL and UL, the spectral efficiency for TDD is reduced from 2.0 to 0.636 bits/s/Hz for DL and from 1.7 to 0.736 bit/s/Hz for UL. The reduced spectral efficiency can affect the number of reports that can be made, especially when there is heavy access load.

6.4.3 Analysis/evaluation of cost reduction

Based on the cost drivers and values for the reference LTE modem in subclause 5.3, the cost savings for each peak rate reduction technique are summarized as following:

1. Reduction of maximum transport block sizes for DL and UL

The cost savings are due to reduced requirements for UL processing, turbo decoding, and HARQ buffering.

2. Restricting the number of PRBs in an assignment/grant

The cost savings are due to reduced requirements for UL processing, turbo decoding, and HARQ buffering.

3. Restricting the maximum modulation order

The cost savings are due to less restrictive power amplifier EVM requirements, local oscillator of RF transceiver, less precision needed for the ADC, simplification of the UL processing block, turbo decoding, post-FFT data buffering, and HARQ buffering.

Table 6.4.3 summarizes the cost savings for Techniques 1, 2 and 3 according to the recommended values for evaluation. In Technique 1, cost savings are derived from the reference Category-1 UE with reduction of maximum TB size for DL or UL to 1000 bits. In Technique 2, cost savings are derived from the reference Category-1 UE restricted to 6PRBs in 20MHz bandwidth carrier (4392 bits downlink and 2600 bits uplink supported TB size). In Technique 3, cost savings are derived from the reference Category-1 UE with restricting the maximum modulation to QPSK for DL or UL. Note that the cost savings estimation is not tied to an individual company evaluation.

Table 6.4.3: Relative cost savings estimation for Technique 1, 2 and 3

Functional block (Ratio of RF to baseband cost 40:60)	Recommended (for Evaluation)	Technique 1 (Relative savings)	Technique 2 (Relative savings)	Technique 3 (Relative savings)
RF				
Power amplifier	25%-30%	NA	NA	0-20%
Filters	5%-10%	NA	NA	NA
RF transceiver (including LNAs, mixer, and local oscillator)	40%-50%	NA	NA	0-10%
Duplexer /Switch	15%-25%	NA	NA	NA
Other	0%-10%	NA	NA	NA
Total of RF	95%-110%	NA	NA	0%-6% for UL 0%-5% for DL 0%-11% for both
Baseband				
ADC / DAC	10%	NA	NA	30%
FFT/IFFT	5%	NA	NA	NA
Post-FFT data buffering	10%-15%	NA	NA	17%-33%
Receiver processing block	20%-35%	NA	NA	NA
Turbo decoding	5%-15%	90%	57%	NA
HARQ buffer	10%-15%	90%	57%	NA
DL control processing & decoder	5%	NA	NA	NA
Synchronization / cell search block	10%-15%	NA	NA	NA
UL processing block	5%-10%	81%	50%	10%
MIMO specific processing blocks	5%-15%	NA	NA	NA
Other	0%	NA	NA	NA
Total of Baseband	90%-110%	4%-8% for UL 13.5%-27% for DL 17.5%-35% for both	2.5%-5% for UL 8.5%-17% for DL 11%-22% for both	0.5%-1% for UL 4.5%-8% for DL 5%-9% for both
Overall relative cost savings		2.5%-5% for UL 8%-16% for DL 10.5%-21% for both	1.5%-3% for UL 5%-10.5% for DL 6.5%-13.5% for both	0%-3% for UL 3%-7% for DL 3%-10% for both

The mechanism for peak rate reduction could have some additional small savings not considered here. For example, eliminating the processing for more than one turbo code block or reducing the number of HARQ processes.

6.5 Reduction of transmit power

6.5.1 Description

Reducing the output power or completely removing the power amplifier stage of an MTC UE is expected to provide cost savings. A reduction in transmit power adversely impacts uplink coverage performance and spectral efficiency. Power consumption will be affected and there will be an impact on specifications. By simply removing the final power amplifier stage, a device's output power is likely to be reduced to the range of 0dBm to +5dBm. Additional chip redesign may allow for a significantly higher output power (exactly how high is FFS).

6.5.2 Analysis/evaluation of performance against requirements

6.5.2.1 Coverage analysis

Reducing the transmit power of a device has a direct impact on the uplink link budget, reducing the uplink coverage of the device compared to a higher transmit power device, meaning coverage requirements cannot be met assuming direct downlink and uplink wide area network access from MTC devices to eNBs. All uplink physical channels will be similarly affected, further contributing to a downlink/uplink link budget imbalance. For example, with the COST231-Hata model, the cell radius reduces 78.2% if the PA is removed and the UE output power is of the order of 0 dBm. Depending on the amount of transmit power reduction, the coverage may be worse than for GSM/EGPRS.

6.5.2.2 Power consumption

Reducing the transmit power may result in a reduction in the device power consumption. State of the art power amplifier devices include self-bias functions that reduce the DC power consumption as the transmit power reduces, however once the power amplifier reaches its minimum bias level, further reductions in transmit power will not result in further reductions in DC power consumption. In order to achieve further reductions in DC power consumption, the removal of the power amplifier can be considered.

For the case of reduced UE transmit power, a reduced MCS would be required in an attempt to restore the uplink link budget, however this would increase the UE transmit duty cycle thus potentially increasing power consumption. Furthermore any schemes used in an effort to restore the uplink link budget may in themselves contribute to an increase in power consumption in the UE.

6.5.2.3 Impact on specification

The reduction of UE transmit power would require the creation of a single or multiple new UE power class(es) with additional definition of related requirements such as MPR and A-MPR levels. This would have impacts on TSG RAN WG4 specifications. It would also be necessary to ensure that existing RF requirements are met.

Restoring uplink coverage would require analysis and support in TSG RAN WG1 and TSG RAN WG2. Unless sufficient uplink coverage can be restored through protocol changes then improved performance requirements for the eNB and/or the UE will need to be considered in TSG RAN WG4.

6.5.2.4 Cell spectral efficiency

If the transmit power for MTC UEs is reduced, lower uplink MCSs have to be used in order to retain LTE uplink coverage. However lower uplink MCSs cause uplink cell spectral efficiency reduction. Furthermore, a reduced transmit power may limit the transmission of UCI thus affecting the downlink cell spectral efficiency. Low-cost MTC UEs with a reduced transmit power are unlikely to meet the spectral efficiency requirement stated in subclause 5.1.

The estimated uplink spectral efficiency reduction provided by the sourcing companies is summarized in Table 6.5.2.4.1.

Table 6.5.2.4.1 Uplink spectral efficiency reduction estimation for reduction of transmit power

Maximum Transmit power	Spectral efficiency calculation	Source 1 (see note 1)	Source 2 (see note 2)	Source 3 (see note 3)
17dBm	Cell			5% (3GPP Case 1) 65% (3GPP Case 3)
	Cell-edge			
10dBm	Cell	19% (3GPP Case 1)	18% (3GPP Case 1) 60% (3GPP Case 3)	
	Cell-edge	85% (3GPP Case 1)	86% (3GPP Case 1) 100% (3GPP Case 3)	
0dBm	Cell	59% (3GPP Case 1)		
	Cell-edge	98% (3GPP Case 1)		

NOTE 1: Analysis assumes TDD in 10MHz with 8 receive antennas at the eNB. Full buffer traffic model.
NOTE 2: Analysis assumes FDD in 10MHz with 4 receive antennas at the eNB. Full buffer traffic model.
NOTE 3: Analysis assumes FDD in 5MHz with 2 receive antennas at the eNB. Regular reporting traffic model (clause A.1).

6.5.3 Analysis/evaluation of cost reduction

The estimated cost savings provided by the sourcing companies are summarized in Table 6.5.3.1. The power amplifier accounts for 25-30% of the cost of the RF module of the reference LTE modem with the RF functional block accounting for 40% of the total cost of the modem. Removal of the power amplifier will result in a 10-12% overall relative cost saving and an output power in the order of 0dBm. A lower saving is seen when the power amplifier is retained but there is a reduction in output power and relaxation in linearity: in this case the saving amounts to 2-7%.

Table 6.5.3.1 Relative cost saving estimation for a reduction of transmit power

Functional block (Ratio of RF to baseband cost 40:60)	Recommended cost breakdown (for Evaluation)	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7	Source 8
Transmit power reduction scheme		Maximum transmit power = 10dBm	Remove the power amplifier: Maximum transmit power = 0dBm	Remove the power amplifier	Remove the power amplifier	Remove the power amplifier	Reduction in output power and relaxation in linearity	Remove the power amplifier	Reduction in output power and relaxation in linearity
RF									
Power amplifier	25%-30%	50%	100%		100%	100%		100%	30%
Filters	5%-10%	NA	NA			NA			
RF transceiver (including LNAs, mixer, and local oscillator)	40%-50%	NA	NA			NA			15%
Duplexer /Switch	15%-25%	NA	NA			NA			
Other	0%-10%	NA	NA			NA			
Total of RF	***95%-110%***	***12.5-15%***	***25-30%***	***30%***	***25%***	***25%***	***5%***	***13%***	***13.5-16.5%***
Baseband						NA			
ADC / DAC	10%	NA	NA			NA			
FFT/IFFT	5%	NA	NA			NA			
Post-FFT data buffering	10%-15%	NA	NA			NA			
Receiver processing block	20%-35%	NA	NA			NA			
Turbo decoding	5%-15%	NA	NA			NA			
HARQ buffer	10%-15%	NA	NA			NA			
DL control processing & decoder	5%	NA	NA			NA			
Synchronization / cell search block	10%-15%	NA	NA			NA			
UL processing block	5%-10%	NA	NA			NA			
MIMO specific processing blocks	5%-15%	NA	NA			NA			
Other	0%	NA	NA			NA			
Total of Baseband	***90%-110%***	***0%***	***0%***	***0%***	***0%***	***0%***	***0%***	***0%***	***0%***
Overall relative cost savings		**5-6%**	**10-12%**	**11%**	**10%**	**10-12%**	**2%**	**5%**	**5-7%**

6.6 Half duplex operation

6.6.1 Description

Half duplex FDD (HD-FDD) operation is a technique that can lower the cost of an MTC UE by simplifying the RF implementation. By not requiring simultaneous transmission and reception, an HD-FDD MTC UE does not require a duplexer: in place of a duplexer a switch is used. It is noted that the eNB still uses full duplex FDD (FD-FDD) operation and will be required to ensure that there are no scheduling conflicts for HD-FDD MTC UEs. This requirement will mean the scheduler needs to consider data and control traffic in both directions when making scheduling decisions for an MTC UE. It is noted that this requirement can add to the complexity of the scheduler. For full duplex UEs, such scheduling restrictions are not needed: this can make concurrent support more complicated. When not in DRX, the MTC UE will continuously receive downlink physical channels except when instructed by the network to transmit in the uplink or when transmitting unscheduled (contention-based) PRACH. A switching time will need to be observed by HD-FDD MTC UEs when transitioning from receive to transmit and vice versa – this will need to be taken into account by the scheduler.

It is noted that TDD UEs do not transmit and receive at the same time and are inherently half duplex in nature. The cost and performance advantages identified in this subclause already apply to Release 8 TDD LTE UEs.

6.6.2 Analysis/evaluation of performance against requirements

6.6.2.1 Coverage analysis

Half duplex operation will result in no loss of coverage. In order to accommodate the UE switching time between downlink subframes that are immediately followed by uplink subframes, the UE may choose not to receive symbols at the end of the downlink subframe, thereby increasing the PDSCH SINR requirements. This SINR loss can be avoided by the scheduler and is compensated for by the improved noise figure of a switch-based receiver RF chain. The scheduler can schedule UEs such that uplink transmissions do not immediately follow downlink transmissions: in this case the UE may receive all the symbols within the downlink subframe. The noise figure of a switch-based receiver RF chain is less than that of a duplexer-based receiver RF chain, allowing HD-FDD UE receivers to be more sensitive than FD-FDD UE receivers. In summary the downlink coverage of an HD-FDD UE is expected to be at least as good as that of an FD-FDD UE.

6.6.2.2 Power consumption

Compared to the reference category 1 LTE modem, power consumption is likely to be reduced. The insertion loss of the switch in the HD-FDD UE is less than in the duplexer of an FD-FDD UE: reducing the electrical power required to produce a certain amount of radiated RF power. Half duplex operation means some components can be put in a reduced power state until required. It is recognised that RF and baseband power consumption is often dictated by implementation.

6.6.2.3 Impact on specification

Some support for half duplex operation was introduced in LTE Release 8. However some further specification work may be required.

TSG RAN WG4 specifications will need to be updated to define at least the following:

- HD-FDD UE performance requirements for the switching time for the downlink-to-uplink and uplink-to-downlink transitions, if deemed necessary by further study in TSG RAN WG1 as explained below.

- In the case of UE implementation where operation is restricted to half-duplex only:

    - Bands in which HD-FDD UEs can operate.

    - Performance requirements for HD-FDD UEs.

From the perspective of TSG RAN WG1, it is recognised that further study is required. This study may lead to specification changes, but some issues may be resolved by implementation. Aspects to consider may include, but are not not limited to, the following:

- UE switching times
    - Switching time for the *downlink-to-uplink* transition is created by allowing the UE to DRX the last OFDM symbols in a downlink subframe immediately preceding an uplink subframe. Whether the switching time should be explicitly defined in the specifications is FFS at the time of introduction..
    - Switching time for the *uplink-to-downlink* transition is handled by setting the appropriate amount of timing advance in the UE. This switching time is important when the UE is close to the cell centre (with near zero timing advance). The same adjustment of the uplink timing from the eNB perspective is also applied to full duplex UEs [6]. It should be further investigated whether specification change is needed to facilitate the eNB in deciding the appropriate amount of timing advance (e.g. by defining UE requirement on maximum allowed switching time).
- Managing of conflict between downlink and uplink transmissions. HD-FDD operation is implemented as a scheduler constraint, implying the scheduler ensures that a UE is not scheduled simultaneously in the downlink and uplink. There are occasions that downlink and uplink transmissions cannot be avoided by scheduler constraints, for example when the UE transmits an unscheduled (contention-based) PRACH that cannot be predicted by the eNB. It is possible that the UE may transmit a PRACH at the same time that it is scheduled via PDCCH/PDSCH in the downlink. In this case the UE will not be able to receive the PDCCH/PDSCH.

6.6.2.4 Cell spectral efficiency

It is apparent that since HD-FDD MTC UEs cannot transmit and receive in the same subframe, there is an impact on the sustained data rates that can be provided to/from a single device. Furthermore in order to accommodate the required switching times for downlink-to-uplink transition at the UE, DRX during the switching times at the UE results in a reduction in downlink capacity. This problem is further compounded given that the switching time for the uplink-to-downlink transition is handled by timing advance that will further impact on the downlink transmissions. The RF noise figure of an HD-FDD UE may be less than for an FD-HDD UE since the HD-FDD UE uses a switch rather than a duplexer. The lower HD-FDD UE noise figure may compensate for the capacity loss associated with the DRX during switching times.

An eNB that supports HD-FDD UEs operates in full duplex mode irrespective of the capabilities of the UEs it is supporting. Given a sufficient number of HD-FDD UEs supported in a cell, the eNB is able to efficiently schedule HD-FDD UEs such that all the PRBs in the subframe can be allocated. Under this assumption it is expected that cell spectral efficiency is not impacted when HD-FDD MTC UEs are supported.

Since there are insignificant cell spectrum efficiency impacts from the support of LTE HD-FDD UEs, the spectral efficiency of an LTE cell is unlikely to be degraded through supporting LTE HD-FDD UEs. Its spectral efficiency is likely to be significantly greater than can be achieved in a GSM/EGPRS network supporting GSM/EGPRS terminals.

6.6.3 Analysis/evaluation of cost reduction

This subclause considers the potential cost saving from implementing a half duplex LTE MTC UE.

A half duplex mode UE does not need a duplexer. Instead of a duplexer a half duplex LTE MTC modem uses a switch. Additional savings from reduced complexity and memory may also be possible in the baseband module. This is because in half duplex mode there is no need to provision processing power and memory for concurrent downlink and uplink operations.

Given that a switch represents a small percentage of the cost of the duplexer, then a high proportion of the cost associated with the duplexer / switch in the RF module can be saved. Given that the duplexer cost is in the range of 15-25% of the RF module (which is 40% of the total LTE reference modem cost), HD-FDD mode provides an overall cost saving based on the reference LTE modem of 4-8%. It is further noted that the potential relative cost reduction may be even larger for multi-band devices (that may have multiple duplexers) than for the assumed single-band reference modem.

The estimated cost savings provided by the sourcing companies are summarized in Table 6.6.3.1. If it is assumed that some cost saving could be achieved due to reduced computational requirements then a 5-10% cost saving may be made in the baseband module: this results in an overall cost saving of 9-12% from source 6. Also if it is assumed that some cost saving could be achievable with RF components optimized for HD-FDD operation that take advantage of relaxation in performance and/or functional requirements (the absence of self transmitter blocking and interference easing filtering rejection requirements) then this results in an overall cost saving of 12-19% from source 7.

Table 6.6.3.1 Relative cost saving estimation for half duplex operation

Functional block **(Ratio of RF to baseband cost 40:60)**	**Recommended cost breakdown (for Evaluation)**	**Source 1**	**Source 2**	**Source 3**	**Source 4**	**Source 5**	**Source 6**	**Source 7**
RF								
Power amplifier	25%-30%			NA	NA			NA
Filters	5%-10%			NA	NA			20%
RF transceiver (including LNAs, mixer, and local oscillator)	40%-50%			NA	NA			20%
Duplexer /Switch	15%-25%		80%	67%	90%	70-80%		80%
Other	0%-10%			NA	NA			NA
Total of RF	***95%-110%***	***15%***	***20%***	***10-17%***	***20%***	***10-20%***	***15%***	***20-32%***
Baseband								
ADC / DAC	10%			NA	NA			NA
FFT/IFFT	5%			NA	NA			30%
Post-FFT data buffering	10%-15%			NA	NA			NA
Receiver processing block	20%-35%			NA	NA			20%
Turbo decoding	5%-15%			NA	NA			NA
HARQ buffer	10%-15%			NA	NA			NA
DL control processing & decoder	5%			NA	NA			NA
Synchronization / cell search block	10%-15%			NA	NA			NA
UL processing block	5%-10%			NA	NA			20%
MIMO specific processing blocks	5%-15%			NA	NA			NA
Other	0%			NA	NA			NA
Total of Baseband	***90%-110%***	***0%***	***0%***	***0%***	NA	***0%***	***5-10%***	***6.5-10.5%***
Overall relative cost savings		**6%**	**8%**	**4-7%**	**8%**	**4-8%**	**9-12%**	**12-19%**

6.7 Reduction of supported downlink transmission modes

6.7.1 Description

For a reference Rel-10 Cat-1 UE, the maximum number of supported layers for spatial multiplexing in downlink is one, and the supportable transmission modes for a reference LTE Rel-10 Cat-1 UEs are TM1-TM9. One potential technique for low-cost MTC UEs is to reduce the supportable downlink transmission modes with a view to eliminating the redundant transmission schemes supported by different TMs and simplifying MTC UE's implementation complexity.

TM1 and TM2 are needed as the basic TMs for backward compatibility.

6.7.2 Analysis/evaluation of performance against requirements

6.7.2.1 Coverage analysis

The reduction of supported downlink transmission modes will not bring link performance loss on PDCCH, but the link performance of PDSCH may be impacted. However, as described in the subclause 6.3, the bottleneck of coverage in downlink is the control channel rather than the data channel, so the downlink coverage for MTC UEs would not be impacted by the reduction of supported downlink transmission modes.

6.7.2.2 Power consumption

Baseband power consumption may be reduced by eliminating the need to support precoding. However, some performance degradation due to the absence of precoding may cause a possible increase of power consumption for MTC UEs. Overall there is not expected to be significant impact on power consumption by the reduction of supported downlink transmission modes.

6.7.2.3 Impact on specification

To support MTC UEs with the reduction of supported downlink transmission modes, minor specification changes may be expected. The feature of reduced downlink transmission modes may appear as a property of the UE category that is mentioned in subclause 6.4, and some modifications on the IEs *UE-EUTRA-Capability* and *AntennaInfoDedicated* in TS 36.331 may be needed.

6.7.2.4 Cell spectral efficiency

There may be some downlink performance degradation due to the lack of precoding gain. Table 6.7.2.4 gives performance degradation results provided by multiple sources. Although performance degradation is expected due to the reduced downlink transmission modes, the impact of downlink performance degradation may be lessened considering the typical MTC traffic model as described in annex A. Moreover, the cell spectral efficiency in the case of MTC UEs with the reduction of supported downlink transmission modes is larger than that of GSM/GPRS.

Table 6.7.2.4: Performance degradation results compared to TM2

	Cell average					**Cell edge**				
	Source 1 [8]	**Source 2 [9]**	**Source 3 [10]**	**Source 4 [11]**	**Source 5 [12]**	**Source 1 [8]**	**Source 2 [9]**	**Source 3 [10]**	**Source 4 [11]**	**Source 5 [12]**
FDD: TM6	3.69%	NA	21%	20% (2Tx) 40% (4Tx)	16.6% (2Tx) 33.1% (4Tx)	15.8%	NA	41%	35% (2Tx) 63% (4Tx)	41% (2Tx) 82.9% (4Tx)
TDD: TM7	18% (4Tx2Rx)	15.4% (8Tx1Rx)	10% (8Tx2Rx)	NA	NA	46.3%	43%	26%	NA	NA

6.7.3 Analysis/evaluation of cost reduction

Potential cost reduction with reduced transmission modes may come from removing DMRS based channel estimation if DMRS based precoding is not supported, no PMI computation if PMI feedback is not supported (either CRS or CSI-RS based PMI) and simplified MIMO detection/equalization algorithm.

Note that the support of DMRS based transmission (which is needed e.g., for ePDCCH and/or new carrier type) may negate cost saving that might be obtained by removing DMRS based transmission scheme(s) for PDSCH. According to the cost breakdown given in subclause 5.3 for the reference LTE modem, Table 6.7.3 gives relative cost saving estimations for the reduction of supported downlink transmission modes from multiple input sources. Note that different cost saving estimations from different sources may be based on different reduction assumptions.

From Table 6.7.3, the range of relative total cost saving with the technique of reduction of supported downlink transmission modes is about 2-10%.

Table 6.7.3: Relative cost saving estimations for reduction of supported downlink transmission modes

Functional block (Ratio of RF to baseband cost 40:60)	Recommended cost breakdown (for Evaluation)	Source 1 [8]	Source 2 [13]	Source 3 [11]	Source 4 [14]	Source 5 [15]
RF						
Power amplifier	25%-30%	NA	NA	NA	NA	NA
Filters	5%-10%	NA	NA	NA	NA	NA
RF transceiver (including LNAs, mixer, and local oscillator)	40%-50%	NA	NA	NA	NA	NA
Duplexer /Switch	15%-25%	NA	NA	NA	NA	NA
Other	0%-10%	NA	NA	NA	NA	NA
Total of RF	95%-110%	0%	0%	0%	0%	0%
Baseband						
ADC / DAC	10%	NA	NA	NA	NA	NA
FFT/IFFT	5%	NA	NA	NA	NA	NA
Post-FFT data buffering	10%-15%	NA	NA	NA	NA	NA
Receiver processing block	20%-35%	48%	30%	11%	25%	15%
Turbo decoding	5%-15%	NA	NA	NA	NA	NA
HARQ buffer	10%-15%	NA	NA	NA	NA	NA
DL control processing & decoder	5%	NA	NA	NA	30%	NA
Synchronization / cell search block	10%-15%	NA	NA	NA	NA	NA
UL processing block	5%-10%	NA	NA	NA	NA	NA
MIMO specific processing blocks	5%-15%	30%	NA	NA	NA	NA
Other	0%	NA	NA	NA	NA	NA
Total of Baseband	90%-110%	16.2%	6-10.5%	2-4%	6.5-10.2%	5%
Overall relative cost savings		**9.7%**	**3.6-6.3%**	**2%**	**3.9-6.3%**	**3%**

7 Cost reduction evaluation summary

Text below provides summary of cost reduction gains and associated coverage and spectral efficiency impacts. Coverage impacts have been analysed for individual and combination of cost reduction techniques in [16] and is summarised in the table 7.1 and the spectral efficiency impact in text below the table 7.1.

Table 7.1: Summary cost and performance (coverage/spectral efficiency) impacts of techniques for cost reduction

	Average degradation to cell coverage	Average overall UE cost reduction gains
Half Duplex FDD (HD-FDD)	None	7%-10%
Uplink Tx power Reduction	>5dB in UL and is proportional to the Tx power reduction	10%-12% (If PA is removed) 2%-7% (If PA is retained)
Transmission mode (TM) reduction (E.g. TM1/TM2 + TM8/9 (Rank 1) only)	None	2%-10%
Peak Rate reduction (TBS 1000 bits)	None	10.5%-21%
Reduced bandwidth (BW) for both RF and baseband for DL and UL. DL-1/UL-1 BW Reduction (1.4 MHz)	1~3dB	~39%
Reduced BW for baseband only for DL and no BW reduction for UL. DL-2/UL-2 BW Reduction (1.4 MHz)	1~3dB	~28%
Reduced BW for only data and only in baseband. No BW reduction for UL DL-3/UL-2 BW Reduction (1.4 MHz)	None	~19%
Single receive RF	4dB	24%-29%
Peak Rate reduction (TBS) + Single receive RF	Same as for Single receive RF (4dB)	42%
Peak Rate reduction (TBS) + DL-1/UL-1 BW Reduction	Same as for BW reduction (1~3dB)	44%
Peak Rate reduction (TBS) + DL-2/UL-2 BW Reduction	Same as for BW reduction (1~3dB)	36%
Peak Rate reduction (TBS) + DL-3/UL-2 BW Reduction	None	26%
Peak Rate reduction (TBS) + DL-1/UL-1 BW Reduction + Single receive RF	5~9 dB	59%
Peak Rate reduction (TBS) + DL-2/UL-2 BW Reduction + Single receive RF	Same as for BW reduction + Single receive RF (5~9dB)	56%
Peak Rate reduction (TBS) + DL-3/UL-2 BW Reduction + Single receive RF	Same as for Single receive RF (4 dB)	50%
TM(1/2+9) + Peak Rate reduction (TBS) + DL-2/UL-2 BW Reduction	Same as for BW reduction (1~3dB)	37%
TM(1/2+9) + Peak Rate reduction (TBS) + DL-2/UL-2 BW Reduction+ Single receive RF	Same as for BW reduction + Single receive RF (5~9dB)	56%
NOTE: Analysis of coverage degradation is for downlink unless explicitly indicated. Transmission bandwidth is reduced to 1.4 MHz for BW reduction techniques unless explicitly specified.		

Single receive RF is expected to be the main technique that, in addition to coverage, impacts spectral efficiency. Impact on spectral efficiency with single receive RF chain has been analyzed in subclause 6.3 with degradation of approx 23% to 25% for FDD and approx 17% for TDD and is dependent on the frequency band.

8 Specification aspects to restrict techniques to only low performance MTC UE.

This clause captures possible solutions to ensure by specification that the techniques discussed in clause 6 and adopted for low-cost MTC UEs are restricted to only low-cost MTC UEs with low data rate and/or high latency tolerance. This restriction is needed in order to ensure that the existing transmission and reception characteristics and performance requirements of non-MTC LTE UEs are not affected by the MTC-specific specification developments. Without this restriction, any simplification may be applied to non-MTC UEs.

8.1 Restricting the techniques to a new UE category

The aim of introducing a new MTC-specific UE category would be to restrict any adopted MTC-related low-cost technique affecting the UE and/or network performance to this new UE category only.

This solution makes sure the existing UE categories are not affected by the simplifications intended for low-cost MTC UEs, by:

- defining a new UE category specifically for low-cost MTC devices, and;

- restricting any simplification technique affecting the UE and/or network performance to operate only with this UE category.

This solution allows the network to identify the UEs which use simplifications affecting the UE or network performance, since the UE reports its category upon initial connection.

This identification would, for example, enable the network to apply specific scheduling policies or specific service handling to these UEs, in order to limit their potential adverse impact on the network performance, or alternatively, it could be considered whether the network can decide to block the UEs from this UE category in case their subscription information does not match with MTC.

In addition, further study would be needed to enable the network to unambiguously bind UEs of the new UE category to only certain MTC-applicable services. Detailed mechanisms for such binding are out of scope of RAN.

The peak rate of the new UE category, as discussed in subclause 6.4, could, for example, be set targeting an appropriate cost reduction objective. It is worth noting that even if peak rate reduction is not finally specified, defining a new UE category as discussed in this subclause could still be justified by the need to identify the UEs with degraded radio performance compared with non-MTC UEs.

9 Coverage improvement

9.1 Description

Some MTC UEs are installed in the basements of residential buildings or locations shielded by foil-backed insulation, metalized windows or traditional thick-walled building construction, and these UEs would experience significantly greater penetration losses on the radio interface than normal LTE devices. The MTC UEs in the extreme coverage scenario might have characteristics such as very low data rate, greater delay tolerance, and no mobility, and therefore some messages/channels may not be required.

Performance evaluation of coverage improvement techniques shall be analyzed in terms of: coverage, power consumption, cell spectral efficiency, specification impacts and, cost or complexity analysis.

Not all UEs will require coverage enhancement, or require it to the same amount. It should be possible to enable the techniques only for the UEs that need it.

9.2 Coverage Analysis

An additional coverage requirement of a 20dB improvement in comparison to "category 1 UEs" is targeted. Table 9.2.1-1 lists the MCL table for category 1 UEs.

Table 9.2.1-1 Summary of MCL from Table 5.2.1.2-2 and Table 5.2.1.2-3 in subclause 5.2.1.2 (unit:dB)

Physical channel name	PUCCH (1A)	PRACH	PUSCH	PDSCH	PBCH	SCH	PDCCH (1A)
MCL (FDD)	147.2	141.7	140.7	145.4	149.0	149.3	146.1
MCL (TDD)	149.4	146.7	147.4	148.1	149.0	149.3	146.9
NOTE 1: eNB is assumed with 2 Tx and 2 Rx in FDD systems. NOTE 2: eNB is assumed with 8 Tx and 8 Rx in TDD systems. NOTE 3: PHICH is neglected and the function of PHICH can be implemented by PDCCH in case of cell edge.							

From Table 9.2.1-1, it can be expected when the amount of coverage improvement becomes larger, all channels listed in Table 9.2.1-1 need to be improved. For example, if the amount equals 20dB, all uplink and downlink channels need to be enhanced because the gap between maximum MCL and minimum MCL is 8.6 dB for FDD and 2.7dB for TDD.

Given that single receive RF and bandwidth reduction might be used for MTC UEs, and these techniques would decrease downlink coverage, additional coverage improvement needs to be considered to compensate this coverage loss.

Assuming an x dB coverage improvement is desired, the limiting channel from Table 9.2.1-1 with the minimum MCL will need to be improved by x dB. Note that x dB coverage improvement is with respect to category 1 UE at the data rate of 20 kbps. The other channels will require less improvement, with the overall amount of compensation equal to x dB reduced by the difference between the MCL and the minimum MCL. The overall amount of compensation should also include the application of low-cost MTC techniques: single receive RF chain would require additional coverage compensation for all downlink channels, and reduction of maximum bandwidth may require additional coverage compensation for the (E)PDCCH and PDSCH.

9.3 Required system functionality

Required system functionality for MTC UEs in enhanced coverage mode is assumed to include functionality needed for synchronisation, cell search, power control, random access procedure, channel estimation, measurement reporting and DL/UL data transmission (including DL/UL resource allocation).

Channels and signals associated with Multimedia broadcast services and location services are not included in the initial phase of study and are excluded from the analysis for coverage improvement.

A MTC user who moves around is unlikely to be out of coverage for long. Study target of coverage improvement is primarily for delay tolerant low-cost MTC device which are not mobile and detailed analysis/evaluation of mobility procedures are excluded from the analysis in this TR

System functionality requirement for large delay tolerant MTC UE requiring enhanced coverage may be relaxed or simplified in comparison to that required by normal LTE UE. Channels associated with such system functionality can then be excluded from detailed analysis/evaluation for study of coverage improvement.

HARQ Ack/Nack for PUSCH transmission is carried by PHICH. Dependent on the technique(s) for coverage improvement PHICH may or may not be required. Control Format Indicator (CFI) in PCFICH is transmitted in each subframe and indicates the number of OFDM symbols used for transmission of control channel information. With some additional complexity in UE (e.g. decoding of control channel assuming different CFI) or higher-layer signalling (e.g. pre-configuration of CFI), PCFICH may be eliminated. Techniques for coverage improvement for PHICH and PCFICH are therefore excluded from analysis in this TR.

9.4 Concepts for coverage improvement

This subclause provides the concepts on coverage improvement techniques focused in this study, and also lists some additional techniques. Analysis and evaluation of the techniques and whether they meet the requirements can be found in subclause 9.5. The list of examples provided in this subclause should not be considered as an exhaustive one.

9.4.1 TTI bundling/ HARQ retransmission/ Repetition/ Code spreading/ RLC segmentation/ Low rate coding/ Low modulation order/ New Decoding Techniques

More energy can be accumulated to improve coverage by prolonging transmission time. The existing TTI bundling and HARQ retransmission in data channel can be helpful. Note that since the current maximum number of UL HARQ retransmission is 28 and TTI bundling is up to 4 consecutive subframes, TTI bundling with larger TTI bundle size (such as extensively investigated in TR 36.824 [18]) may be considered and the maximum number of HARQ retransmissions may be extended to achieve better performance. Other than TTI bundling and HARQ retransmission, repetition can be applied by repeating the same or different RV multiple times. In addition, code spreading in the time domain can also be considered to improve coverage. MTC traffic packets could be RLC segmented into smaller packets; very low rate coding, lower modulation order (BPSK) and shorter length CRC may also be used. New decoding techniques (e.g. correlation or reduced search space decoding) can be used to improve coverage by taking into account the characteristics of the particular channels (e.g., channel periodicity, rate of parameter changes, channel structure, limited content, etc.) and the relaxed performance requirements (e.g. delay tolerance).

9.4.2 Power boosting / PSD boosting

More power can be used by the eNB on the DL transmission to a MTC UE (i.e., power boosting), or a given level of power can be concentrated into a reduced bandwidth at the eNB or the UE (i.e., PSD boosting). The application of power boosting or PSD boosting will depend on the channel or signal under consideration.

9.4.3 Relaxed requirement

The performance requirements for some channels can be relaxed considering the characteristics (e.g., greater delay tolerance) of MTC UEs at extreme scenarios. For the synchronization signal, MTC UEs can accumulate energy by combining PSS or SSS multiple times, but this will prolong acquisition time. For PRACH, a loosened PRACH detection threshold rate and a higher false alarm rate at eNB could be considered.

9.4.4 Design new channels or signals

New design of channels or signals for better coverage is possible if implementation based schemes cannot meet coverage improvement requirement. These channels and signals, together with other possible link-level solution for coverage enhancement, are summarized in Table 9.5-1.

9.4.5 Small cells for coverage improvements

Coverage enhancements using link improvements must be provided for scenarios where no small cells have been deployed by the operator. An operator may deploy traditional coverage improvement solutions using small cells (including Pico, Femto, RRH, relays, repeaters, etc.) to provide coverage enhancements to MTC and non-MTC UE's alike. In deployments with small cells, the path loss from the device to the closest cell is reduced. As a result, for MTC devices, the required link budget can be reduced for all channels. Depending on the small cell location/density, the coverage enhancement in subclause 9.2 of this TR may still be required, although possibly to a smaller degree.

For deployments that already contain small cells, there may be a benefit to further allow decoupled UL and DL for delay tolerant MTC UEs. For UL, the best serving cell is chosen based on the least coupling loss. For DL, due to the large Tx power imbalance (including antenna gains) between the Macro and LPN, the best serving cell is the one with maximum received signal power. This UL/DL decoupled association is feasible for MTC traffic especially for services without tight delay requirements. To enable UL/DL decoupled operation either in a UE-transparent or non-transparent manner, macro serving cell and potential LPNs may need to exchange information for channel (e.g. RACH, PUSCH, SRS) configurations and to identify the suitable LPN. A different RACH configuration may be needed with decoupled UL/DL, from that without decoupled UL/DL.9.4.6.

9.4.6 Additional techniques

Existing solutions that are deployed for coverage improvement for "normal LTE UE" such as directional antennas, and external antennas can improve coverage for MTC UE and normal UE alike. Further enhancements to such solutions to improve MTC UE coverage exploiting the specific MTC UE application characteristics are not excluded.

9.5 Analysis of Physical Channels and Signals

This subclause provides analysis of coverage improvement techniques for various physical channels. List of possible link-level solutions for coverage enhancement of various physical channels are summarised in Table 9.5-1

Table 9.5-1: Possible link-level solutions for coverage enhancement of physical channels and signals

Channels/Signals Solutions	PSS/SSS	PBCH	PRACH	(E)PDCCH	PDSCH/ PUSCH	PUCCH
PSD boosting	x	x	x	x	x	
Relaxed requirement	x		x			
Design new channels/signals	x	x	x	x	x	
Repetition		x	x	x	x	x
Low rate coding		x		x	x	x
TTI bundling/Retransmission					x	
Spreading		x			x	
RS power boosting /increased RS density		x		x	x	
New decoding techniques		x				

9.5.1 PSS/SSS

9.5.1.1 Coverage enhancement

According to subclause 9.2 of this TR, the coverage for PSS/SSS needs to be improved 11.4 dB for FDD and 17.4 dB for TDD in order to achieve an overall coverage enhancement target of 20 dB.

Simulations based on the assumptions listed in Table 9.5.1.1-1 show that this coverage improvement can be achieved by non-coherent accumulation of the existing PSS/SSS signals with a longer sync acquisition time than that for normal LTE UEs. Initial synchronization (i.e., timing, frequency, and cell ID acquisition) requires up to 2 seconds per center carrier frequency for FDD, and possibly longer than this for TDD which needs about 6 dB more coverage improvement for PSS/SSS. Re-synchronization can be performed quicker than initial synchronization.

Table 9.5.1.1-1: Simulation assumptions for PSS/SSS evaluation

Parameter	Value
System bandwidth	1.4 MHz
Frame type	FDD or TDD
Carrier frequency	2.0 GHz for FDD / 2.6 GHz for TDD
Antenna	2x2, low correlation for FDD / 8x2, low correlation for
Channel model	EPA
Doppler spread	1 Hz or 2 Hz
Frequency error	1 kHz or 20 kHz
Performance target	10% miss probability

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Furthermore, PSD boosting can be considered a complementary solution. A new PSS/SSS signal may need to be considered if the longer sync acquisition time and associated power consumption increase are not considered acceptable.

9.5.1.2 Impact on specification

Sync acquisition based on the existing PSS/SSS signals requires no changes in RAN1 specifications. Note that there is no direct requirement in RAN4 on synchronization acquisition time which is only part of the inter- or intra-frequency RSRP/RSRQ measurement requirement defined in 3GPP TS 36.133 for mobility support. MTC devices in need of coverage enhancement may have no mobility.

PSD boosting can be considered a network implementation choice, but it should be noted that it will also affect legacy UEs.

Introduction of a new PSS/SSS signal for enhanced coverage mode would have specification impact in particular in RAN1.

9.5.1.3 Other impacts

UE power consumption for sync acquisition is related to the required number of repetitions that need to be received. Cell spectral efficiency and UE cost are unaffected by a longer acquisition time.

Introduction of a new PSS/SSS signal for enhanced coverage mode will degrade cell spectral efficiency and increase cost as the existing PSS/SSS signals are anyway required for non-MTC UEs and non-enhanced coverage MTC UEs.

9.5.2 PBCH

9.5.2.1 Coverage enhancement

The coverage target of PBCH may be addressed by

1) A combination of repetition of the current PBCH in subframe #0 of a radio frame onto every subframe of that radio frame (i.e., a new PBCH structure) and PSD boosting (e.g., 4 dB) within 40 ms (for FDD systems)

– The repetition alone cannot meet the coverage target for the current PBCH where MIB changes every 40ms due to SFN update (e.g., as many as 36~95 repetitions of the current PBCH in a radio frame are needed).

2) A new PBCH design (for TDD and FDD systems)

– A new design can consider techniques such as: a longer period, reduced legacy MIB content, intermittent transmission. Repetitions and/or PSD boosting may be helpful for new design in order to meet the coverage target.

– Also other system information that is required to be broadcasted to enhanced coverage MTC UEs beside MIB contents can be considered in the new PBCH design.

– Other low rate coding schemes or spreading can be considered for new design.

3) A complementary PBCH decoding technique (e.g., correlation decoder or reduced search space decoder).

The coverage target for PBCH according to subclause 9.2 of this TR is 11.7 dB for FDD and 17.7 dB for TDD. Observable diminishing returns are summarized in Table 9.5.2.1-1 with realistic channel estimation.

Table 9.5.2.1-1: Observable diminishing returns for PBCH repetitions and / or PSD boosting

Source 1*	Source 2**	Source 3***	Source 4**	Source 5**
With 4dB PSD boosting (both CRS and PBCH): 40 transmissions / 12 dB 20 transmissions / 10 dB 8 transmissions / 6.5 dB Without PSD boosting: 110 transmissions / 11.7 dB 47 transmissions / 8.7 dB 24 transmissions / 6.7 dB 11 transmissions / 3.7 dB	Without PSD boosting: 80 repetitions / 11.8 dB 40 repetitions / 10.1 dB 20 repetitions/ 7.8 dB	PSD boosting (only PBCH): 6 PRBs / 1.9 dB 18 PRBs / 3.3 dB 42 PRBs / 4.7 dB	With 3dB CRS boosting: 40 repetitions / 11.7 dB 11 repetitions / 6.7 dB	With 3dB PSD boosting (both CRS and PBCH): 10 repetitions / 11.1 dB 5 repetitions / 8.5 dB 2 repetitions / 5.7 dB

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NOTE :

*: The pair X / Y indicates the number X of transmissions of a single subframe of the current PBCH and the achieved gain Y relative to the current PBCH (4 subframes).

**: The pair X / Y indicates the number X of repetitions of four subframes of the current PBCH and the achieved gain Y relative to the current PBCH.

***: The pair X / Y indicates the number X of PRBs (other than the central 6 PRBs) that need to be unloaded and the achieved gain Y relative to an unboosted PBCH. The channel estimation is based on unboosted CRS.

9.5.2.2 Impact on specification

For repetition of the current PBCH in a new structure or a new PBCH design, the resources for mapping repetitions are required to be specified. It may impact the resource mapping of other channels (e.g., (E)PDCCH/PDSCH) when they also map to the center 6 PRBs

For a new design, depending on the considered techniques, specification impact may include the length of a longer period, the content conveyed in the new broadcast channel design, parameters used for intermittent transmission (e.g., duration and gap of transmission intervals), and spreading or other low rate coding schemes.

Further study could determine if there is impact on specifications of using UE implementation-based solutions such as decoding techniques.

9.5.2.3 Other impacts

Power consumption will be increased and cell spectral efficiency will be decreased due to additional resources required to transmit the PBCH. To meet the coverage target in subclause 9.2 of this TR, repetition of the current PBCH in a new mapping structure (or even in certain new PBCH designs) could consume substantial resources in the center 6 PRBs (e.g., an increase from one subframe per radio frame to all the 10 subframes in the radio frame, and with additional 4dB boosting). PSD boosting by unloading other PRBs may degrade cell spectral efficiency. Note that spectral efficiency is defined based on full cell loading. Lightly-loaded network, where spectral efficiency may not be the main concern, may have spare resource to accommodate the large PBCH overhead.

The general techniques of repetition and PSD boosting are not expected to increase UE cost. Depending on the new PBCH design, there may be some additional UE cost.

Further study could determine if there are impacts on power consumption, and UE cost of using UE implementation-based solutions such as decoding techniques. The current analysis shows that no cell spectral efficiency degradation is expected for UE implementation-based solutions (e.g., decoding techniques), but more study is required.

9.5.3 PRACH

9.5.3.1 Coverage enhancement

Subclause 9.2 of this TR indicates that PRACH coverage needs to be enhanced by 19dB (FDD) and 20 dB (TDD), when 20dB extra overall coverage enhancement is targeted. PRACH can use techniques such as: repetition, design new preamble format, and relaxed requirement.

- The extra coverage target of PRACH can be achieved as an example, by preamble repetition of about 200 times and/or new preamble format.

- PRACH performance is characterized by probability of miss (Pmiss) and probability of false alarm (Pfa). Relaxing Pfa would cost additional downlink resources to transmit random access response (RAR) for false detection. Relaxing Pmiss will make it easier to meet the coverage target, and can be used in addition to repetition and/or new preamble format. PRACH coverage target can be met by about 100 repetitions combined with relaxing Pmiss from 1% to 10%.

- It can be observed that relaxing Pmiss from 1% to 10% and with about 32 sequence repetitions, 17dB coverage enhancement target could be achieved, and with about 10 sequence repetitions and 4 sequence repetitions 14 dB and 11dB coverage enhancement target can be achieved respectively.

It should also be noted that:

- In order to avoid excessive repetitions, the number of repetitions may be adjusted based on the UE's actual coverage status. PRACH can be used to inform eNB on the amount of coverage enhancement a low-cost MTC UE needs. For example, the system/eNB can pre-define/broadcast the mapping between PRACH resource and the amount of necessary coverage enhancement.

- As a complement to the other techniques, PSD boosting over a narrower bandwidth could be further studied. Initial simulation results show PSD boosting provides no coverage enhancement benefit.

9.5.3.2 Impact on specification

Coexistence with legacy UEs (e.g. collisions probability, resource allocation) is required to be considered when discussing schemes like preamble repetition and/or new preamble format. The number of repetitions as well as the starting subframe should be predefined or configured by higher layer signalling. The latency of PRACH would be increased by applying preamble repetition and/or new preamble format and relaxed requirement of Pmiss. In order to reduce collision probability between coverage limited MTC UEs and legacy UEs, dedicated resource for coverage limited MTC UEs is expected. PSD boosting over a narrower bandwidth may result in a new sequence design.

9.5.3.3 Other impacts

Other than specification impact, impacts such as power consumption, cell spectral efficiency and analysis/evaluation of cost reduction were identified:

- UE power consumption: Power consumption will be increased by preamble repetition or sequence repetition.

- Cell spectral efficiency: Cell spectral efficiency is decreased dependent on the percentage of coverage limited MTC UEs and the number of preamble or sequence repetitions.

- Analysis/evaluation of cost reduction: The general techniques of preamble repetition, new preamble format, relaxing PRACH performance and PSD boosting are not expected to significantly impact the related UE Tx side cost. On the eNB Rx side, new PRACH resources are needed.

9.5.4 (E)PDCCH

9.5.4.1 Coverage enhancement

PDCCH (format 1a) needs to be enhanced by 14.6 dB for FDD and 19.6dB for TDD, similarly for EPDCCH with similar number of REs. The coverage target can be achieved by repetition of (E)PDCCH across multiple subframes. Other techniques, for example, PSD boosting, compact DCI, higher aggregation level, can help to reduce the required number of repetition.

Repetition of (E)PDCCH across multiple subframes may be required to achieve the coverage enhancement target. Simulation results show that around 100-200 repetitions at the aggregation level of 8 CCEs can achieve the coverage target of PDCCH (format 1a). Similar result is expected on EPDCCH. Other new design of downlink control channel can help to reduce the required number of repetitions, but repetition may still be needed based on the study. For example, compact DCI format and higher aggregation level can reduce the required number of repetitions from 100 (8 CCEs and 29 bits DCI payload) to 20 (16 CCEs and 9 bits DCI payload). PSD boosting, on (E)PDCCH or the demodulation RS, can also help to reduce the required number of repetitions.

Compact DCI formats can improve the coverage, e.g., about 1.7-2.4 dB coverage gain can be provided by reducing DCI format size from 29/27 bits to 9/10 bits. Increasing aggregation level from 8 CCE to 16 CCE can provide 2-2.8 dB gain. 9dB PSD boosting of PDCCH can provide up to 5.1 dB coverage extension when channel estimation is based on non-power boosted CRS.

9.5.4.2 Impact on specification

In order to support repetition of (E)PDCCH across multiple subframes, specification impact is expected, given that (E)PDCCH is currently sent in one subframe. Specification impact may include specification of starting subframe of first transmission and the maximum number of repetitions. With repetition required for (E)PDCCH and PDSCH, the current timing relationship between PDSCH and (E)PDCCH (i.e., both are encapsulated in the same subframe except for SPS) also needs to be revisited. The same may also apply to the (E)PDCCH and PUSCH timing relationship.

For EPDCCH, PSD boosting may be applied with no specification impact due to the use of DMRS. For PDCCH, the degree of specification impact would depend on the details of how PSD boosting is introduced (i.e., on CRS and/or data), even though the UE does not need to be aware of CRS boosting for QPSK demodulation. RAN4 specification impact from PSD boosting on PDCCH/EPDCCH or the demodulation RS could arise from the larger variation in transmit power across subcarriers and its effects on EVM requirements.

Compact DCI formats or higher aggregation levels will have some specification impact, such as for definition of new DCI format and redesign of search space to support higher aggregation levels.

9.5.4.3 Other impacts

Repetition of (E)PDCCH across multiple subframes will result in increased latency and increased overhead for the actual traffic payload to be conveyed. Small MTC packet payload may result in an even larger proportional overhead for control channel and CRC. The control overhead needs further analysis, concerning the overall system efficiency optimization.

The impact on power consumption due to (E)PDCCH processing is expected to come from prolonged reception time in RF and baseband due to repetition across subframes.

The cost impact of MTC UEs may largely depend on the buffer size required to store received data and LLRs. Depending on the processing time and the gap between repetitions, MTC UEs may need some additional buffer in the case (E)PDCCH is repeated across subframes.

9.5.5 PUCCH

9.5.5.1 Coverage enhancement

The coverage target for PUCCH (format 1a) is 13.5 dB for FDD and 17.3 dB for TDD. Time domain repetition can be applied to PUCCH for coverage improvement. The exact repetition number depends on the PUCCH format employed. For PUCCH format 1a, simulation results show 50~ 100 times repetition is needed for FDD based on different BLER target.

PUCCH carries UCI which includes Scheduling Request (SR), HARQ-ACK and CSI. Repetition times could be shortened if some of these contents are reduced or eliminated. In general, the necessity of supporting PUCCH for MTC UEs in extreme coverage scenario could be further evaluated.

9.5.5.2 Impact on specification

To support time domain repetition, minor specification impact on HARQ-ACK timing is expected. If some or all of the contents of PUCCH is reduced or eliminated, some specification impacts could be anticipated. For example, if HARQ-

ACK is eliminated, impact on HARQ retransmission is expected. With SR elimination, impact on PRACH collisions probability may need to be considered. There could also be impact on corresponding downlink control information (DCI) optimization.

9.5.5.3 Other impacts

No significant impact on UE cost and complexity is expected with time domain repetition. Other impacts, such as increased UE power consumption, decreased cell spectral efficiency and longer demodulation latency at eNB could be expected.

9.5.6 PDSCH

9.5.6.1 Coverage enhancement

Repetition in time domain, RS power boosting, increased RS density and PSD boosting can be applied to PDSCH for coverage improvement.

The estimated repetition times provided by the sourcing companies to achieve PDSCH coverage improvement target are summarized in Table 9.5.6.1-1 for FDD and Table 9.5.6.1-2 for TDD. The evaluation assumptions are listed in Table 9.5.6.1-3.

Table 9.5.6.1-1: Repetition times to achieve PDSCH coverage improvement target for FDD

Source	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7	Source 8	Source 9	Source 10	Source 11
Repetition times	55	100~200	330	80	145	65	400	200	42	100	100

NOTE 1: Source 8 assumes 20Hz frequency error and all other sources assume 100Hz frequency error

NOTE 2: Source 2 and Source 9 use single subframe channel estimation, other sources use realistic cross-subframes channel estimation.

Table 9.5.6.1-2: Repetition times to achieve PDSCH coverage improvement target for TDD

Source	Source 1	Source 2	Source 3
Repetition times	160	256	290

NOTE 3: All sources use realistic cross-subframes channel estimation.

Table 9.5.6.1-2: Simulation assumptions of PDSCH

Parameter	Value
UL-DL configuration (For TDD)	0
Carrier frequency	2GHz for FDD/2.6GHz for TDD
Antenna configuration	2x2, low correlation for FDD; 8x2, low correlation for TDD
Channel model	EPA
Doppler spread	1Hz
MCS	0
Number of DL RBs	6
Transmission mode	TM2
Frequency tracking error	100Hz
Performance target	10% iBLER
Channel estimation	Realistic cross-subframes or single-subframe channel estimation
The minimum required SINR	-19.3dB for FDD; -25.3 dB for TDD

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Evaluation results vary among sourcing companies due to different receiver processing algorithms including different cross-subframe channel estimation algorithms.

The observations from these evaluation results provided in Table 9.5.6.1-1 and Table 9.5.6.1-2 are summarized as follows:

- The coverage target for PDSCH can be met by time domain repetition
- The average repetition time to achieve the coverage improvement target is 100~200 for FDD and 200~300 for TDD
- Cross-subframe channel estimation requires less number of repetition times than single-subframe channel estimation.

In addition, RS power boosting and/or increased RS density may further improve the channel estimation performance. Initial evaluation results from 2 sourcing companies show about 1dB gain from 3dB CRS power boosting or doubled CRS density. PSD boosting can help to improve the coverage. Initial evaluation results from one sourcing company show 5dB gain from 9dB PSD boosting based on CRS without CRS power boosting and 8.4dB gain from 9dB PDSCH and DM-RS boosting.

9.5.6.2 Impact on specification

Some specification impact is expected due to time domain repetition depending on the specific schemes, e.g. TTI bundling, HARQ retransmission etc. TTI bundling needs to be introduced in downlink if it is adopted to achieve time domain repetition which will impact TSG RAN1, RAN2 and/or RAN4 in terms of, for example, configuration of bundling window, composition of repeated subframes, etc. Also, (E)PDCCH overhead optimization may also have impacts on PDSCH specification.

RS power boosting and PSD boosting are currently supported. If higher RS power boosting or PSD boosting is introduced, some specification impacts on TSG RAN1, RAN2 and/or RAN4 are expected. Increasing RS density is expected to cause significant impact on TSG RAN1 specifications.

9.5.6.3 Other impacts

Time domain repetition prolongs UE reception time which will cause more UE power consumption. RS power boosting, increased RS density or PSD boosting is not expected to cause more UE power consumption.

Time domain repetition will cause significant cell spectral efficiency degradation since more physical resources will be occupied for a single packet transmission. CRS power boosting, increased CRS density or PSD boosting will degrade cell spectral efficiency since the power of other REs is reduced or even eliminated as long as the power at eNB is not increased. DM-RS power boosting or increased DM-RS density may not necessarily degrade cell spectral efficiency depending on the concrete design.

The UE cost is not expected to significantly increase by adopting time domain repetition, RS power boosting, PSD boosting or increased RS density.

9.5.7 PUSCH

9.5.7.1 Coverage improvement

Repetition, increased DMRS density, PSD boosting, frequency hopping (during repetition), shorter length CRC and code spreading are identified as techniques to enhance PUSCH for coverage. One or more solutions among those identified techniques can be used for enhanced PUSCH coverage. It is expected however that repetition technique may be needed regardless of other techniques applied or not to achieve coverage enhancement.

The estimated repetition times to achieve PUSCH coverage improvement target are analyzed and summarized in Table 9.5.7.1-1 for FDD and Table 9.5.7.1-2 for TDD. The evaluation assumptions are listed in Table 9.5.7.1-3.

Table 9.5.7.1-1 Repetition times to achieve PUSCH coverage improvement target for FDD

Source	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7	Source 8	Source 9
Repetitions/TBS/ achieved SINR	219/20/-21.3dB 559/104/-21.2dB	300/16/-20.7dB	620/32/-21.3dB 730/56/-21.3dB 1160/104/-21.3dB	300/16/-22dB	1050/16/-19.3dB	250/16/-21.3dB	1000/160/-19dB	93/42/-19.3dB	100/16/-19.5dB 150/32/-20.5dB 150/32/-20dB 150/40/-19.8dB

NOTE 1: Source 2 and Source 8 use single subframe channel estimation, other sources use realistic cross-subframes channel estimation.

Table 9.5.7.1-2 Repetition times to achieve PUSCH coverage improvement target for TDD

Source	Source 1
Repetitions/TBS/achieved SINR	210/56/-27dB 90/24/-25dB

NOTE 2: Source 1 uses realistic cross-subframes channel estimation.

Table 9.5.7.1-3 Simulation assumptions of PUSCH

Parameter	Value
System bandwidth	10MHz
UL-DL configuration (For TDD)	0
Carrier frequency	2GHz for FDD/2.6GHz for TDD
Antenna configuration	1x2, low correlation for FDD; 1x8, low correlation for TDD
Channel model	EPA
Doppler spread	1Hz
Number of UL RBs	1
Transmission mode	TM1
Frequency tracking error	100Hz
Performance target	10% iBLER
Channel estimation	Realistic cross-subframe channel estimation or single-subframe channel estimation
The minimum required SINR	-24.3 dB for FDD; -30.3 dB for TDD; note that this minimum required SINR is achieved by 2 PRBs transmission

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Evaluation results vary among sourcing companies due to difference on achieved SINR, selection of TBS and different receiver processing/algorithm in terms of cross-subframe channel estimation.

The observations from these evaluation results provided in Table 9.5.7.1-1 and Table 9.5.7.1-2 are summarized as follows:

- The coverage target for PUSCH can be met by repetition

- For 1 PRB carrying 16-104 bits (i.e., required SINR = -21.3dB for FDD and -27.3dB for TDD), repetition time to achieve the coverage improvement target is within a range of around 200~1200 (relatively larger amount of repetition is required compared to PDSCH)..

- The required number of repetition also depends on the selected TBS and the number of transmission PRBs.

- Cross-subframe channel estimation requires less number of repetition times than single-subframe channel estimation.

- Selection of TBS needs to consider the spectral efficiency and channel coding gain.

In addition, PSD boosting (e.g., by allocating 1 PRB instead of 2 PRBs or by using fewer than 12 subcarriers in each PRB) may further reduce the number of repetitions (initial evaluation results show about 20% ~ 30% repetition can be saved by using 1 PRB than 2 PRBs). Increased DMRS density (e.g., doubled DMRS symbols) can also reduce the number of repetitions to achieve coverage gain.

In addition, frequency hopping (during repetition) and shorter length CRC can bring additional coverage gain. Code spreading can also be considered to improve the coverage.

9.5.7.2 Impact on specification

For the support of repetition, PSD boosting, and frequency hopping, some specification impact is expected while some corresponding fundamental operation such as TTI bundling, PSD boosting, frequency hopping are already being supported in current specification. Introduction of extended PUSCH bundling window and corresponding UL HARQ timeline and/or design of frequency hopping pattern combined with repetition will impact RAN1, RAN2 and/or RAN4.

For the support of increased DMRS density, code spreading, and shorter length CRC, relatively larger specification impact is expected since those solutions may have to go with new design, further evaluations and/or estimation on potential impacts. Those solutions are expected to cause some impacts on RAN1, RAN2 and RAN4 while design of increased DMRS density or code spreading will mainly impact RAN1 and introduction of shorter length CRC will mainly impact RAN2.

9.5.7.3 Other impacts

Repetition and code spreading prolongs UE transmission time which will cause more UE power consumption. Increased DMRS density, PSD boosting, frequency hopping, and shorter length CRC is not expected to cause more UE power consumption.

Repetition will cause significant cell spectral efficiency degradation since more physical resources will be occupied for a single packet transmission to accumulate more energy or obtain more coding gain. Increased DMRS density, PSD boosting, frequency hopping, and shorter length CRC are not expected to cause significant cell spectral efficiency degradation. Code spreading may cause spectral efficiency degradation depending on scheduling in eNB (i.e. whether multiple UEs with different code are to be multiplexed within a same PRB) or limited supportable packet size (e.g. up to 20 bits if existing PUCCH format 3 design is reused).

The UE cost/complexity is not expected to significantly increase by adopting repetition, increased DMRS density, PSD boosting, frequency hopping, shorter length CRC and code spreading.

Besides, impact to the eNB receiver is expected, for example, for schemes like long code spreading and changes to DMRS density.

10 Conclusion and recommendations

Cost reduction techniques have individually been analyzed in clause 6 and further cumulative reduction has been analyzed, for cost reduction and coverage impact in clause 7 of this TR.

There are uplink and/or downlink coverage impacts for some of the proposed cost reduction techniques. E.g. Reduction in uplink transmit power significantly impacts uplink coverage performance and single receive RF chain impacts downlink coverage performance.

Uplink transmit power reduction impacts UL spectral efficiency in comparison to normal LTE operation. Single receive antenna may have impact on DL spectral efficiency depending on the frequency band and antenna performance in comparison to normal LTE operation. Spectral efficiency for both UL and DL is expected to be better for low data rate MTC traffic with either or both of these techniques compared to that achieved for R99 GSM/EGPRS terminals in GSM/EGPRS networks today.

Some bandwidth reduction options have relatively large impact on specification of Radio Interface architecture and protocols; some of these aspects may be covered by the Enhanced DL control channel(s) work item. Reduced uplink transmit power and single receive RF chain may have relatively large impact for specification of radio performance aspect's.

No eNodeB hardware upgrade is envisaged for any of the studied techniques. Support of cost reduction techniques is also envisaged to reduce power consumption cumulatively. Among the techniques studied, except for half duplex FDD, no other techniques result in degradation to latency for HARQ operation.

Bill Of Material cost of LTE UE modem would be comparable to EGPRS modem if e.g. downlink bandwidth is reduced to 1.4 MHz, if downlink transmission modes are reduced, half duplex FDD is adopted, peak data rate is reduced with TBS restricted to 1000 bits and Single Rx chain is adopted.

Among the three techniques studied for peak data rate reduction, reduction of maximum transport block sizes for DL and UL (technique 1) has higher cost savings compared to other two techniques. Note that technique 3 ("restricting the maximum modulation order") is not a recommended technique.

At least Peak rate reduction with TBS restricted to 1000 bits and bandwidth reduction with transmission bandwidth reduced to 1.4 MHz are recommended as cost reduction techniques for low-cost MTC UE. Transmission bandwidths of 3MHz and 5 MHz are not excluded if there is severe degradation in coverage when combined with other techniques e.g. single receive RF, though it is desired to preserve the cost savings. Half duplex FDD is expected to be supported at least as an optional feature for UE category specified for low-cost MTC devices. Since peak uplink transmission power reduction cannot meet the coverage requirements defined in the study item: it is not recommended as a cost saving technique for a low-cost MTC device. In addition, coverage reduction should be entirely compensated to ensure same service coverage as LTE for the coverage limiting channel(s) with other techniques as a pre-requisite for adopting single receive RF chain or combinations including them.

In addition, it is recommended to introduce an MTC-specific UE category and to restrict any MTC-related low-cost adopted technique to this new UE category only, as described in subclause 8.1.

Coverage improvement techniques that can improve coverage for delay tolerant MTC UE in FDD and TDD systems have been studied and link level solution(s) to improve coverage for various physical channels and signals have been analysed in clause 9 of this TR. For deployments where small cells are already deployed, an additional technique for coverage improvement based on UL/DL decoupling is studied in subclause 9.4.5 of this TR.

The analysis of coverage improvement from various techniques for the studied physical channels show additional coverage improvement target of 20dB targeted by the study can be achieved with techniques studied in subclause 9.4 of this TR.

Protocol and RF Specification impact for each of the techniques applicable to respective physical channels/signals has been analysed in subclause 9.5 of this TR along with other impacts such as UE power consumption, UE cost sensitivity of the technique and spectral efficiency impact. Required system functionality has been analysed in subclause 9.3 of this TR.

Not all delay tolerant MTC UE's are expected to be in bad coverage or require the same coverage improvement. A mechanism to identify and inform eNB the amount of coverage the MTC device requires is studied in subclause 9.5.3.1 of this TR. It is desirable that technique(s) for coverage improvement support scalability of spectral efficiency impact and also the mechanism allow that.

The larger the required improvement to coverage, and for some channels larger the number of MTC UE's in bad coverage, larger is the spectrum efficiency impact (although it has been found that this is not necessarily a linear relationship),specification impact and cost/power consumption impact. It is recommended that further work on techniques should consider these factors.

The coverage enhancement target should be balanced with other considerations (e.g., spectral efficiency, power consumption, cost impact and specification impacts). Considering the spectrum efficiency, specification impact and standardization effort, possible target of coverage enhancement in terms of trade off could be 15 dB at least for FDD.

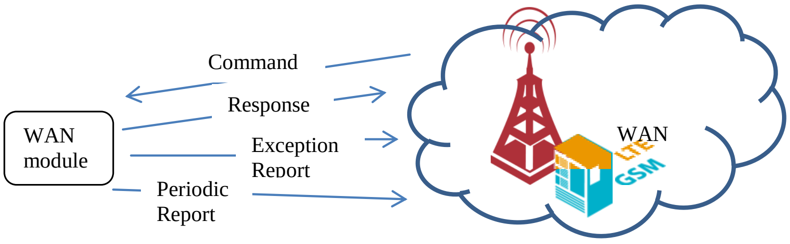
Annex A:
Traffic model for Machine-Type Communications

Traffic characteristics may be required for cost analysis for comparing features of an MTC UE set against the environment in which the device is expected to work. A traffic model is valuable when it comes to other aspects of the analysis that are within the scope of the study item, particularly relating to the quantification of spectrum efficiency.

Some of the typical MTC type Traffic are characterised by small packets in downlink and uplink. Certain applications are in addition characterised by heavy access load in uplink. Below clause A.1 is based on traffic characteristics specified in TR 37.868.

End to End latency achievable should be determined from analysis/evaluation and should be no worse than (E)GPRS and preferably comparable to LTE The analysis/evaluation shall determine the number of UE's that can report. When considering the 20dB improvement in coverage in comparison to defined LTE cell coverage footprint engineered for "normal LTE UEs", latency from trigger to response 5 seconds in the exception report scenario and 10 seconds in the triggered report scenario is allowed.

For reference, in the analysis of smart metering applications, the three scenarios/use cases below are useful.



A. Command-response traffic (triggered reporting) between base station and WAN module; ~20bytes for command (Downlink) & ~100 bytes for response (uplink) with a latency of 10seconds from command sent from eNB to response received by eNB. 10 seconds of round trip latency is shared between downlink and uplink message with frequency of daily to monthly. Example use case: Energization status message, Consumer messaging.

B. Exception reported by WAN module; Report (Uplink) could be ~100 bytes with latency of 3-5 seconds from event at the WAN module. Example use case: Meter alerts (Tamper, fire) etc. with frequency of daily to monthly

C. Periodic reports or Keep alive; ~100 bytes (Uplink) and not sensitive to latency (E.g. tolerance of 1 hour) with frequency of daily to monthly. Example use case:, Power (Kw), Volume (gas e.g. m3), Micro generation read, etc. with frequency of daily to monthly

For reference, numbers of smart meters assuming household density from London [19] and Tokyo [20] census data are shown below.

London:

Case	Household Density per Sq km	ISD (m)	Number of device within a home	Number of homes within a cell
Dense Urban	[4275]	[500]m	3	[926]
Urban	[1517]	[1732]m	3	[3941]

Tokyo:

Case	Household Density per Sq km	ISD (m)	Number of device within a home	Number of homes within a cell
Dense Urban	[7916]	[500]m	3	[1714]
Urban	[2316]	[1732]m	3	[6017]

A.1 MTC Traffic model/characteristics regular reporting

Table A.1: UL regular reporting traffic characteristics for low-cost MTC

Use cases	UL interval	Packet (bits)	Mobility
No mobility	1min (optional) 5min, 30min, 1hour	1000, optional 10000	Static, Pedestrian (optional, no seamless handover requirement)
Limited mobility	5s (optional) 10s, 30s	1000	Vehicular (no seamless handover requirement)

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A.2 MTC Traffic model/characteristics triggered reporting

Below is a generic traffic model modeling both UL and DL.

Table A.2 – MTC traffic model

Traffic model parameter (UL and DL)	Value
Traffic volume size distribution (Triggered)	256 bits, 1000 bits
Traffic inter-arrival time (Triggered)	Exponential: Mean = 30secs*

* It should be noted from Table A.2.1 that the values for 'Traffic transmission time' and 'Traffic inter-arrival time' result in a tractable simulation run time but may not represent the behavior of all traffic types.

Annex B: Change history

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
2011-10	R1#66b	R1-113616			Initial Draft		0.1.0
2012-02	R1#68	R1-120796			Draft to include Evaluation methodology, Traffic model & place holders for some concepts that may provide significant cost savings.	0.1.0	0.2.0
2012-02	R1#68	R1-120930			Draft to include Further TP for Link budget, evaluation methodology, GSM/EGPRS Spectral efficiency, LTE Reference modem cost breakdown & place holders for some concepts that may provide significant cost savings.	0.2.0	0.3.0
2012-03	RP#55	RP-120270			Presentation to RAN#55 Plenary for information	0.3.0	1.0.0
2012-05	R1#69	R1-122959			Include TP's with updates to LTE TDD link budget analysis, bandwidth reduction, Single Rx RF chain, Reduction of peak rate, Reduction of uplink Tx power, Half-Duplex operation,	1.0.0	1.0.1
2012-06	R1#69	R1-123075			Editorial revisions, Include TP to clause 6.7,7,8,9. Update spectral efficiency degradation numbers with reduced Peak rate and reduced modulation order for TDD in sub-clause 6.4.2.5. Remove Square brackets for MCL calculation in Table 5.2.1.2-3.	1.0.1	1.0.2
2012-06	RP#56	RP-120714			Submitted to RAN#56 Plenary for Approval (but not approved)		2.0.0
2013-05	R1#73				Update TR with techniques for coverage improvement and conclusion of study of coverage improvement for Low-cost MTC UEs	2.0.0	2.1.0
2013-06	RP#60	RP-130727			Submitted to RAN#60 Plenary for Approval	2.1.0	2.1.0
2013-06	RP#60	RP-130798			MCC clean-up, and additional rapporteur editorials.	2.1.0	2.1.1