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RP-151550

Narrowband Cellular-IoT (NB-CIoT): The clean-slate technology for the Internet of Things

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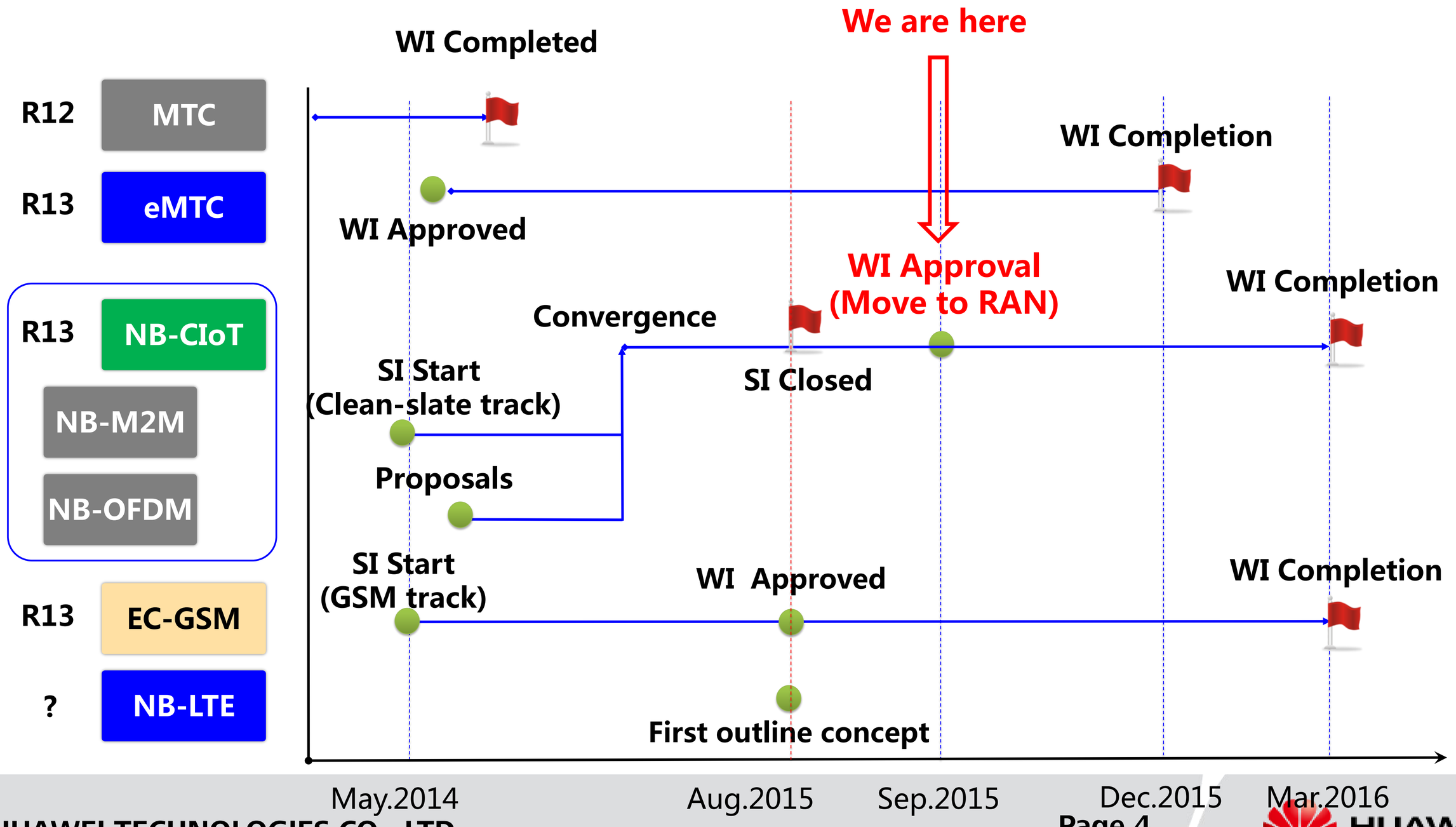
- **CIoT Standard status**
- **Comparison between NB-CIoT and NB-LTE**
- **View on way forward in RAN#69**

Urgency of time to market for LPWA technology

- **GERAN study item is to address LPWA market requirements which have clear objectives as below**
  - Improved indoor coverage (20dB)
  - Support of massive number of low throughput devices (52547 devices per cell by mixed traffic models)
  - Reduced device complexity (much lower cost than GPRS chipset)
  - Improved power efficiency (10 years battery life)
  - Co-existence is feasible to GSM/UMTS/LTE system (In band deployment is not required in the GERAN study)
- **The PCG#34 April 2015 approved decision in PCG34_39r2 is to respect to this urgent LPWA market which is also strongly requested by GSMA. The most important decisions from PCG for the Clean Slate Track:** (in GERAN study item description in GP-140421 clean slate solution is explained as "a non-legacy based design" which means not a legacy design from existing 3GPP radio technologies)
  - One Clean Slate WI can be proposed for approval at RAN#69
  - Such a WI proposal will not be subject to the regular RAN prioritization, it will be done in parallel to the existing RAN WG work/capacity (no TU's discussion; no schedule constraints due to the existing work).
  - TSG RAN should strive to complete the work (if necessary adding AH meetings to keep the work schedule) within R13
  - GERAN approved a GERAN Evolution proposal for normative work(EC-GSM).
- **The performance objectives from GERAN study shall not be relaxed to ensure competence in LPWA market requirement**
  - Solutions which are not compliant with the performance objectives shall not be considered as a clean slate solution serving for LPWA market
  - Incomplete solutions which are keen on compliance with LPWA market requirement shall make a full study before going to WI phase
  - Solutions chasing after in band deployment with potential degradation of performance shall be regarded as further evolution over eMTC WID

3GPP Standard Progress



Conclusion of GERAN study

Key conclusions (in GP-151022) are:

- NB-CIoT is the only completed clean-slate technique, and was shown to be compliant with all performance and compatibility objectives
- EC-GSM is also a completed technique, and was shown to be compliant with all performance and compatibility objectives
  - But assumes 2.4 MHz system bandwidth, has much less capacity in reports/hour/200kHz, requires 10 dB more UE transmit power for the same coverage, and does not offer a good solution after GSM re-farming
- NB-LTE, NB-M2M, NB-OFDMA, N-GSM, C-UNB are partially described techniques

Objective	Completed techniques		Partially described techniques				
	EC-GSM	NB-CIoT	NB-LTE	NB-M2M	NB-OFDMA	N-GSM	C-UNB
Improved indoor coverage (20dB)	Compliant	Compliant	Expected to be fulfilled	Compliant	Compliant	Expected to be fulfilled	Not compliant
Support of massive number of low throughput devices (52547 devices per cell by mixed traffic models)	Compliant	Compliant	Inconclusive/FFS	Compliant	Expected to be fulfilled	Inconclusive/FFS	Not compliant
Reduced device complexity (much lower cost than GPRS chipset)	Compliant	Compliant	Inconclusive/FFS	Expected to be fulfilled	Expected to be fulfilled	Expected to be fulfilled	Not compliant
Improved power efficiency (10 years battery life)	Compliant	Compliant	Inconclusive/FFS	Compliant	Compliant	Inconclusive/FFS	Not compliant
Latency (exceptional report within 10 seconds)	Compliant	Compliant	Expected to be fulfilled	Compliant	Compliant	Compliant	Not compliant
Co-existence with GSM/UMTS/LTE	Compliant	Compliant	Inconclusive/FFS	Expected to be fulfilled	Expected to be fulfilled	Expected to be fulfilled	Not compliant
Impact on GSM/EDGE BTS hardware	Compliant	Compliant	Inconclusive/FFS	Expected to be fulfilled	Expected to be fulfilled	Compliant	Not compliant

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Key messages on NB-LTE

- **NB-LTE was a last-minute proposal submitted to GERAN, based on LTE**
  - The underlying concept for NB-LTE is to re-use LTE as much as possible. Therefore, the concept description is adopted into TR 45.820 as a separate chapter 7A, which is a different section than Sec 7 clean slate solution.
  - However, due to some key differences between Cellular IoT and eMTC/LTE, it is actually very difficult to re-use many aspects of the eMTC and LTE design – so a large amount of standardization effort is still required.
- **NB-LTE proposal is incomplete and only evaluated to a very limited degree in GERAN.**
  - Proper evaluation to same level of maturity as other proposals in GERAN would need ~9 additional months of study, and even more for an in-band deployment option.
  - TR 45.820 captured many areas for FFS. It has not been proven that NB-LTE can meet any of the Study Item objectives (see the Conclusions of the SI). No coexistence analysis for any scenarios was provided.
- **Operation using in-band LTE spectrum is very challenging, unproven, and unlikely to meet the performance objectives defined in Cellular IoT study**
  - NB-LTE in-band deployment was claimed in GERAN but the proponents did not provide the detailed design and there were no in-band performance evaluations or any coexistence analysis.
  - Huawei submitted a paper in GP-150871 containing detail analysis explaining the challenges of in-band deployment for NB-LTE design (such as limited PSD boosting, non-orthogonality of uplink, etc.) and the drawbacks in terms of performance. No answers to these key questions were provided.

Overview of NB-CIoT and NB-LTE

	Downlink		Uplink	
	NB-LTE	**NB-CIoT**	**NB-LTE**	**NB-CIoT**
Multiple access	OFDMA	OFDMA	SC-FDMA	FDMA
Frame structure	M-frame 60ms M-subframe 6ms	Frame 1.28s Subframe 160ms		
Sub-carrier spacing	15 kHz	3.75 kHz	2.5 kHz	5 kHz
Number of sub-channels	12	48	72	36
Maximum transmit power	43 dBm	43 dBm (1/1 reuse) 38 dBm (1/3 reuse)	23 dBm	23 dBm
Modulation mandatory	BPSK, QPSK	BPSK, QPSK	BPSK, QPSK	GMSK
Modulation optional	16QAM	16QAM	16QAM	BPSK, QPSK, 8PSK
FFT size	128	64	128	-
Sampling rate	1.92MHz	240kHz	320kHz	240kHz
Cyclic prefix	9/10 samples (4.7/5.2us)	6 samples (25us)	9/10 samples (28.125/31.25us)	None
FEC	CC	CC	Turbo	Turbo
PAPR (dB)	7.8	7.9	5.7 dB	0 dB
DC overhead	8.3%	2%	-	-

NB-LTE has higher sampling rate, more overhead, and cannot support large cell sizes

Performance comparison between NB-LTE vs NB-CIoT

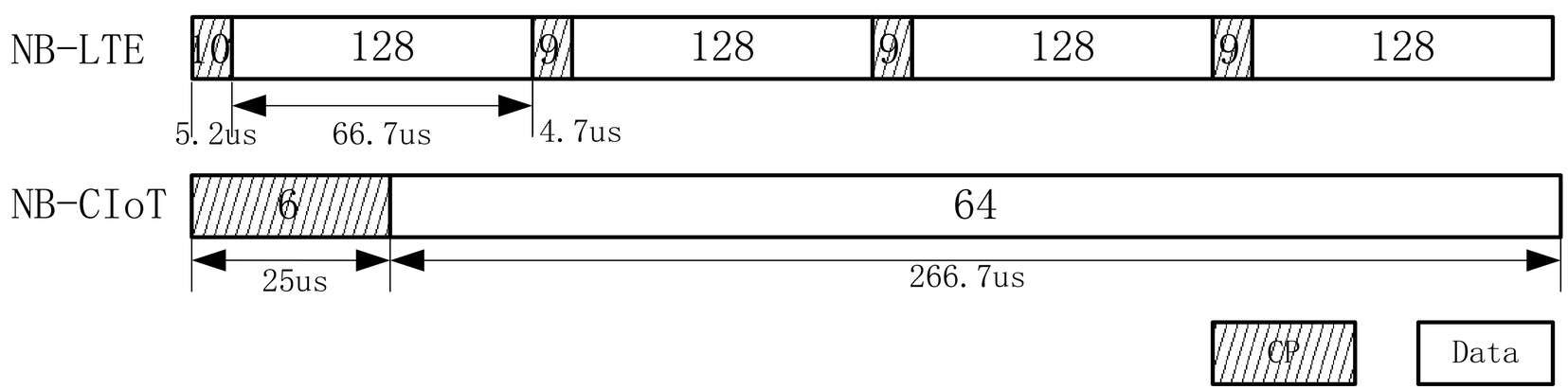
	NB-CIoT	NB-LTE
Coverage enhancement	20dB	20dB (for stand-alone deployment)
Battery life	>10 years	Not shown, probably ~10 years
Re-farm GSM	Yes	Not shown, but problem with Tx mask
LTE in-band (in PRBs)	Not shown	Not shown
LTE guard-band deployment	Yes, shown in trial	Likely
Capacity	>50k devices/sector	Not shown
Data rate	DL: 0.45 to 360 kbps UL: 0.3 to 48 kbps	DL: 0.3 to 128 kbps UL: 0.22 to 64 kbps
Frequency re-use	Flexible: Re-use factor 1/3 or 1 within 200 kHz	Relies on re-use factor 1 within 200 kHz but inter-cell interference not modelled
Scalability	Yes	Yes
Maturity of solution	Good, concept description and evaluation completed in study item	Last-minute proposal: much of the detailed design and most of the evaluation is missing
Standardization effort	Medium	Immature solution
Base station baseband complexity	Low	Medium
Re-use of RRU	LTE only RRU, MSR RRU, GSM MCBTS RRU	LTE only RRU, MSR RRU, cannot re-use GSM MCBTS RRU
Future proof	Yes	Yes

Device Complexity – Why is NB-CIoT cheaper?

	NB-CIoT	NB-LTE
Complexity Analysis of synchronisation (key driver of complexity for chipset baseband)		
PSS+SSS operations	45 Mops/sec	> 585 Mops/sec
Buffer memory	28 kbytes	> 63 kbytes
Implementation Cost Analysis		
Single-die SoC	Yes, using ~512 kbyte embedded flash	No, due to need of external memory (many Mbytes LP-DDR due to large LTE L1/L2/L3 stack)
Software-defined Modem	Yes, low cost DSP is enough	No, the sampling rate is high, so higher processing power is needed especially for PSS/SSS synchronization.
Low-cost CPU	Yes, ARM M0 is enough	TBD, the protocol is more complex and has tighter turn-around times which define peak CPU loading.
Battery	Low instantaneous current draw allows wide range of battery technologies	Higher cost, due to higher PAPR of SC-OFDMA which requires higher instantaneous current draw
On-chip PA	Yes, due to high efficiency PA since modulation is zero or low PAPR	No, SC-OFDMA may have 5dB PAPR; PA efficiency is 35% lower than GMSK.
Low cost radio architecture	Yes, direct conversion receiver and low bandwidth polar modulator transmitter	No, direct conversion receiver is not possible if all DL subcarriers are used; modulation is discontinuous phase and higher PAPR, so requires Cartesian transmit
Overall Cost of Solution	Lower than GSM (about 50% complexity reduction for SoC)	Marginally lower than eMTC, but higher than GSM and much higher than NB-CIoT

Benefits of NB-CIoT Downlink Design

- **NB-LTE with DL 15kHz has 128 IFFT points while NB-CIoT with DL 3.75kHz has 64 IFFT points.**



NB-LTE sampling rate: 128 (fft_size) X 15kHz = 1.92MHz
NB-CIoT sampling rate: 64 (fft_size) X 3.75kHz = 240kHz

- **ADC sampling rate for 15kHz (1.92 MHz) is x8 that for 3.75kHz (240 kHz)**
- **Doubtful feasibility for all presented NB-LTE PSS designs**

Benefits of NB-CIoT Uplink Design

- **Uplink GMSK reduces module cost by ~$1 compared with 23dBm NB-LTE**
  - Allows integrated PA into SoC (PA operates in saturation with high efficiency)
  - Continuous phase modulation allows simple transmitter architectures
  - GMSK is extremely popular in ultra-low cost technologies such as Bluetooth, Bluetooth Smart, Zigbee, Sigfox, LoRa, and a huge number of proprietary systems operating in licensed-exempt bands
    - Low complexity, low cost, high integration, good performance when high data rates is not the key consideration
    - Compatible with wide variety of battery types suitable for IoT products, due to lower peak current consumption

- **Uplink GMSK has better performance and lower power consumption**
  - More robust to multi-user interference, while uplink single subcarrier SC-FDMA is easily affected by multi-user interferences
  - PA efficiency of GMSK is much higher than LTE PA due to 0dB PAPR of GMSK, which is important for battery life and peak current consumption

Table 1: PA Efficiency of GSM PA

Part Number	Frequency	PA Efficiency
SKY77351-13	GSM900	55
SKY77350-13	GSM900	55
SKY77344	GSM900	52
SKY77340	GSM900	53
SKY77336	GSM900	52
SKY77328	GSM900	56

Table 2: PA Efficiency of LTE PA

Part Number	Frequency	PA Efficiency
SKY77708	777-798	36
SKY77707	698-716	36
SKY77449	777-798	36

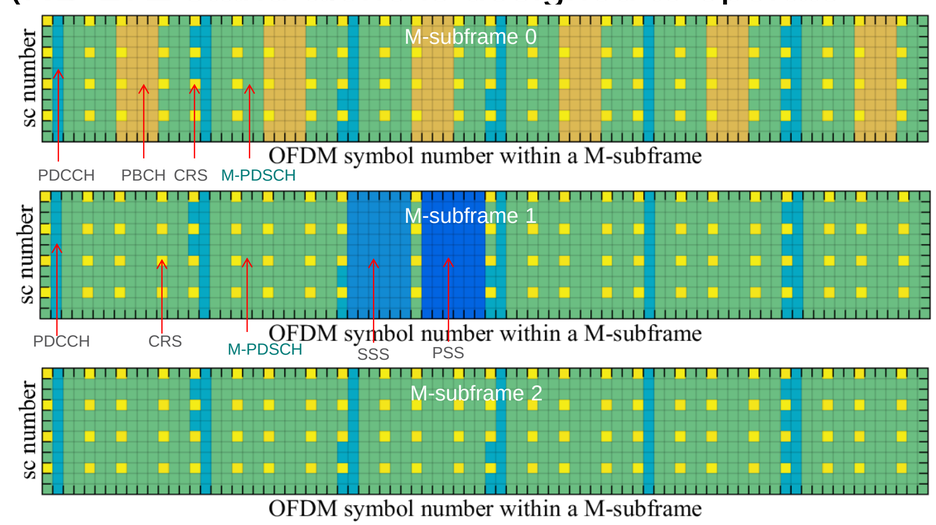
Source: Skyworks web

Integrated in LTE network –NB-CIoT is feasible

- **NB-CIoT can be integrated in LTE network because:**
  - Common core network based on S1 interface
    - Common S1-based protocol structure and
    - Common OAM and OSS with NB-CIoT as a specific carrier in LTE system
  - Common BBU
    - Reuse LTE L2/L3 functions and procedures
    - The required computational complexity for NB-CIoT is tiny compared to that for LTE, software upgrade is feasible
  - Can be integrated in LTE band with common RRU
    - NB-CIOT can be deployed in the LTE guard band
    - The worst case equivalent downlink PAPR of NB-CIoT is only 7.33 dB which is remarkably lower than the PAPR tolerance of a typical LTE BS
  - Common solution design for standalone deployment and LTE guard band deployment

NB-LTE design cannot support in-band deployment with 20dB coverage enhancement and massive number of devices per cell

- **Limitation in downlink transmit power**
  - Maximum PSD boosting of about 4 dB is realistic when deployed in-band.
  - The resulting MCL is 13 dB and 16 dB lower than that for stand-alone deployment with LTE bandwidth of 10 MHz and 20 MHz, respectively.
  - Even if more repetitions are used, the resulting data rates will be too low to be useful (<<100 bps).
  - PSCH may fail to work at the extremely low SNR of -17.6 dB and -20.6 dB (NB-LTE stand-alone is designed to operate at SNR = -4.6dB).
- **Collision with LTE channels/signals** (~30% loss to avoid collision)
  - NB-LTE PSS/SSS collides with LTE PDCCH/CRS/CSI-RS
  - NB-LTE PDCCH/EPDCCH collides with LTE PDCCH/CSI-RS
  - NB-LTE PBCH collides with LTE CSI-RS
  - eMBMS is difficult to support by LTE when NB-LTE is deployed in-band (since PMCH is a wideband transmission at L1)
- **Uplink interference from LTE subcarriers**
  - Orthogonality is not maintained between uplink LTE subcarriers and NB-LTE subcarriers. The 10 kHz guard band introduced by NB-LTE is insufficient to counter the side-lobe leakage of the LTE sub-carriers.



References to GERAN key documents

- GP-150869: Comparison of Downlink PAPR between NB-CIoT and NB-LTE
- GP-150870: Comparison of Base Station Complexity between NB-CIoT and NB-LTE
- GP-150871: On In-band Deployment of NB-LTE
- GP-150872: On M-PDCCH/M-EPDCCH Design in NB-LTE
- GP-150875: Analysis on the re-use of L2/L3 of LTE for NB-CIoT

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Overall Summary

- **The PCG in April 2015 have decided that upon the completion of the Ultra Low Complexity and Low Throughput Internet of Things (CIoT) GERAN study item:**
  - To continue the GSM Evolution track normative work under GERAN
  - To move the Clean Slate (NB-CIoT) track normative work under TSG RAN

- **GERAN#67 August 2015 completed the CIoT study item**
  - GERAN has already approved the GSM Evolution Track work item
  - NB-CIoT Clean Slate solution is fully evaluated and compliant with SI objectives. NB-CIoT work is proposed for approval, as per the PCG directive.

- **Last minute proposal on NB-LTE was submitted to GERAN#67 in the closing meeting of a 15 month study item**
  - NB-LTE proposal was not properly evaluated and is incomplete. It should not be considered now.

- **CIoT is very important feature for operators. Time to market in Rel13 is key for market success and to ensure early entry into some of the vertical markets.**

Way forward

- **WID discussion**
  - NB-CIoT WID should be approved as the only Rel-13 clean slate, compliant, and complete solution.
  - NB-LTE proposal is an incomplete 3rd track study and not clean slate. It should not be considered now.

- **Meeting scheduling for NB-CIoT**
  - Parallel session required for RAN1/RAN2/RAN4
  - For each session in regular meetings: at least 2 days (better 3 days) are allocated to NB-CIoT
  - 2 ad-hoc meetings are considered for RAN1/RAN2/RAN4 for 5 days
    - 14 – 18 December 2015
    - 11 – 15 January 2016
  - 1 ad-hoc meeting is considered for RAN3
    - 11 – 15 January 2016

THANK YOU