TESTNG TECHNIQUES FOR NB-IOT PHYSICAL LAYER

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Abstract

The term Internet of things encompasses everything connected to the internet. The idea of internet of things scales from home appliances to industrial usage. In the coming few years, almost billions of devices are expected to be a part of IoT. IHS forecasts that the IoT market will grow from an installed base of 15.4 billion devices in 2015 to 30.7 billion devices in 2020 and 75.4 billion in 2025.

Narrow Band- Internet of things (NB-IoT) is a way of connecting several devices in an automated manner using existing cellular networks. Devices need to be low cost, and also use less power to extend battery life for which 3GPP has embraced several LPWA (Low Power Wide Access) technologies, such as, NB-IoT. NB-IoT is a non-backward compatible variant of E-UTRAN supporting a reduced set of functionality to limit data rates and support high number of devices per cell.

To help meet the requirement of low power and enhanced coverage extensions, several enhancements have been introduced, mostly in the PHY layer with respect to LTE. These enhancements will as a result help network operators to cater close to 50K devices per cell considering LPWA and increasing power gain by 20dB for the NB-IoT devices.

However, testing these enhancements can be challenging in a controlled environment. In this document, we will be addressing the testing insights for these new implementations in PHY layer under controlled and/or simulated environment. Below are the key areas:

- Testing NB-IOT Coverage enhancement
- Testing Co-existence with existing LTE/ GSM Networks
- Capacity Testing

NB-IoT Physical Layer

In Narrow band internet of things, there are 3 major operational modes defined in 3GPP release 13:

- LTE In-Band operational mode
  - In-Band Same Cell id [00]
  - In-Band Different Cell id [01]
- LTE Guard Band operational mode [10]
- Standalone operational mode [11]
LTE-InBand Operational mode
For In-Band operational mode, the 100 KHz raster implies that an anchor carrier can only be placed in certain PRBs. For example, in a 20 MHz LTE carrier, the indexes of the PRBs that are best aligned with the 100 kHz grid and can be used as an NB-IoT anchor carrier are 4, 44, 55, 95, etc. The NB-IoT UE is configured for +2.5Khz and +7.5Khz raster offset. The PRB indexing starts from index 0 for the PRB occupying the lowest frequency within the LTE system bandwidth.

LTE- Guard Band Operational mode
In addition to LTE-InBand operational mode, in Guardband operational mode the PRBs used fall in the Guardband of LTE spectrum.

Standalone Operational mode
Standalone operational mode uses GSM band and the channel bandwidth remains 200 KHz

Narrow Band Carriers
- Anchor carrier: In NB-IoT, a carrier where the UE assumes that NPSS/NSSS/NPBCH/SIB-NB are transmitted.
- Non-anchor carrier: In NB-IoT, a carrier where the UE does not assume that NPSS/NSSS/NPBCH/SIB-NB is transmitted.

Downlink Reference signal and synch signals
The downlink narrowband reference signal consists of known reference symbols inserted in the last two OFDM symbols of each slot for NB-IoT antenna port 0 and 1, except invalid sub-frames and sub-frames transmitting NPSS or NSSS.
There is one narrowband reference signal transmitted per downlink NB-IoT antenna port. The number of downlink NB-IoT antenna ports equals 1 or 2.
Physical layer provides 504 unique cell identities using the narrowband secondary synchronization signal.
It is indicated whether or not the UE may assume the cell ID is identical for NB-IoT and LTE. In case the cell IDs are identical, a UE may use the downlink cell-specific reference signals for demodulation and/or measurements when the number of NB-IoT antenna ports is the same as the number of downlink cell-specific reference signal antenna ports.
Downlink multi-antenna transmission
Transmit diversity, specifically space frequency block coding (SFBC), is supported if two NB-IoT antenna ports are used.

Synchronization signals
NB-IoT is based on following signals transmitted in the downlink: the primary and secondary narrowband synchronization signals.
The narrowband primary synchronization sequence is transmitted over 11 sub-carriers from the first subcarrier to the eleventh subcarrier in the sixth subframe of each frame, and the narrowband secondary synchronization sequence is transmitted over 12 sub-carriers in the NB-IoT carrier in the tenth subframe of every other frame.

Physical channels in NB-IoT
Narrowband Physical broadcast channel (NPBCH): The coded BCH transport block is mapped to sixty four subframes within a 640 ms interval; 640 ms timing is blindly detected, i.e. there is no explicit signalling indicating 640 ms timing.
Narrowband Physical downlink shared channel (NPDSCH): Carries the DL-SCH and PCH for NB-IoT UEs.
Narrowband Physical downlink control channel (NPDCCH): Informs the NB-IoT UE about the resource allocation of PCH and DL-SCH; Carries the uplink scheduling grant for the NB-IoT UE.
Narrowband Physical uplink shared channel (NPUSCH): Carries the UL-SCH and Hybrid ARQ ACK/NAKs in response to downlink transmission for the NB-IoT UE.
Narrowband Physical random access channel (NPRACH): Carries the random access preamble for the NB-IoT UE.

In NB-IoT cross subframe scheduling has been implemented. Which ensures that no 2 channels overlap or are scheduled in a single SF. Below is a representative diagram of how cross SF scheduling works.

Also, Multiple SF for one TB and multiple repetition of one TB has been implemented in NB-IoT PHY to help meet the requirements for LPWAN. By increasing the repetitions in the channels, better SNR can be achieved in case of poor signal strength.
Challenges in testing NB-IoT PHY layer

Additional functionality, as mentioned above, introduced for NB-IoT brings in additional complexities which require distinct testing techniques to validate them. The major challenges introduced due to these additional functionalities as follows:

- **Testing coverage enhancement functionalities.** In this, NB-IoT modem/ eNodeB are expected to increase or decrease the number of repetitions per channel to support low power devices. The repetitions will be tested in UL and DL for which specific SINR performance has to be validated.
- **Testing co-existence with existing network.** As discussed above in the introduction section, NB-IoT can work in LTE as well as GSM Bands. The major challenge here will be to configure and test the performance in terms of interference pattern keeping LTE or GSM legacy UEs in the scenario
- **Testing Capacity UEs** for NB-IoT will require enhancing the number of UEs supported to about 50K. This support will be a challenge in terms of scheduling the UEs in simulated environment given the cross subframe scheduling rules in NB-IoT PHY.

To overcome the above mentioned challenges, few techniques have been addressed in this document.

**Test bed for testing NB-IoT PHY**

Below setup diagram addresses a common way for testing NB-IoT eNodeB PHY layer. Automation Framework will command Operation and Maintainence entity, to configure the device under test and also the simulators. The test outputs from the logging engine can be analysed through automation agents for various parameters like EVM, Throughputs etc. This setup is practiced with few assumptions:

- UE PHY simulator is NB-IoT compliant (e.g. AF TM500)
- Higher layer simulator can generate MAC PDUs for PHY
- Signal analyser/ generator is licensed for NB-IoT
Testing NB-IoT Coverage enhancement

Testing NB-IoT Coverage enhancement will require less number of UEs to load any specific functionality and the major focus area will be the UEs close to cell edge. With these functionalities, UEs with minimum coverage can experience higher Signal to Noise Ratio (SNR) with more number of channel repetitions configured for those UEs. The key parameters to look into for this area will be mostly specification (e.g. 3gpp) compliant. Few of them have been listed below:

- Signal to Noise ratio
- Error vector magnitude
- Channel bandwidth in UL and DL with signal offset from LTE centre frequency
- QPSK/ BPSK modulation constellation plots
- Measured RSRP at UE PHY simulator
- CRC pass/fail for TBs received in UL by eNB PHY
- Location of TBs in frequency and time domain
- DL BLER per UE in UE PHY Simulator
- DL Decodes by UE PHY simulator

The setup required to test coverage enhancement performance, will require few assumptions:

- Checking simulator is introduced to reduce the signal strength
- Higher layer simulator is capable to support channel repetitions in PHY

Example scenario:

Configuration:

- Number of UEs – 1
- Operational Mode – LTE-InBand SameCellId
- NB PRB IDx - 44
- LTE BW – 20Mhz
- NPBCH/ NPSS/ NSSS/ SIB1/ SI are present in Fixed Frame format
- Number of Legacy UEs – 0

Test:

Configure NB eNB PHY with different NPDSCH repetitions varying across simulation time

Result:

The SINR must vary with increase or decrease in the NPDSCH repetitions.

<table>
<thead>
<tr>
<th>Nrep</th>
<th>0</th>
<th>32</th>
<th>512</th>
<th>2048</th>
</tr>
</thead>
<tbody>
<tr>
<td>SINR</td>
<td>-10 dB</td>
<td>5 dB</td>
<td>17 dB</td>
<td>23 dB</td>
</tr>
</tbody>
</table>
Testing Co-existence

Testing the NB-IoT PHY with existing networks like LTE and GSM can be complication when we consider only PHY layer as the software under test and all other modules/layers are in simulated manner. Testing this area can be done in 2 methods:

- To combine the signals of LTE and NB-IoT and produce a frequency combined signal as described below. Though this approach will not address interference issues for NB-IoT eNB PHY but can address UE behaviour and in turn signalling impact caused in the UL by the UEs

- To combine the LTE and Narrow band signals in the software or in the HW/RF Controller

Example scenario:

Configuration:
- Number of UEs – 1
- Operational Mode – LTE-InBand SameCellId
- NB PRB Idx - 44
- LTE BW – 20Mhz
- NPBCH/ NPSS/ NSSS/ SIB1/ SI are present in Fixed Frame format
- Number of Legacy UEs – 1
- PRBs configured for Legacy UE – 99(Excluding PRB Idx 44)

Test:
- Configure UE simulator with 1 legacy UE and 1 NB UE for HARQ/ PDCP mode.
- Activate both the UEs to perform cell search
- Load the PHY with maximum possible NPDSCH Transmissions
- Configure the UE Simulator to transmit UL for LTE and NB UEs

Result:
1. Both the UEs should be able to decode MIB, SIB1 and SI
2. No BLER observed on legacy and NB UE
Testing Capacity UE

Testing Capacity UEs will ensure the stability and robustness of the PHY layer for maximum load. Though in field/real time scenario, the eNodeB/modem is not expected to be loaded all the UEs at all times. Given the scheduling procedures in NB-IoT, testing Capacity UEs will require extra-long durations and testing of several possible configurations.

Though as the test bed will be having simulated entities, some plausible limitations are expected, such as:

- Simulation length in time domain. As the scheduling will require scenarios spreading across multiple hyper-SFN. There can be a limitation in simulators.
- Logs capture length. As mentioned above, the same limitation can be applicable to logging engines used.

The key KPIs that need to be analysed when testing PHY for Capacity UEs –

- BLER average
- BLER per UE
- Average throughput per cell
- Average throughput per UE
- Alarms, if generated
- Memory utilization
- CPU Utilization

Testing capacity UE will require a NB-IoT capable UE simulator with capability of ~50K UEs. Array of AF TM500 (E500) can be configured with the same Cell Id and frequency to achieve capacity UEs. Each TM500 supports 1K UEs considering 2 cells on single TM500 chassis with each cell supporting 500 UEs.

Example scenario:

Configuration:

- Number of UEs – 50,000
- Operational Mode – Standalone
- NPBCH/ NPSS/ NSSS/ SIB1/ SI are present in Fixed Frame format
- Number of Legacy UEs – 0

Test:

Schedule the NB Ues in DL without any repetitions. An example shown below:

| TM500 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 |

Result:

1. No Assert is observed
2. No BLER is observed
3. Memory and CPU utilization in under threshold boundary

Conclusion

Narrow Band Internet of things technology observes a major and complex change in physical layer implementation. A wider as well as in-depth testing of PHY layer for NB-IoT plays a crucial role before the product is commercially rolled out. The above mentioned techniques will ensure all the basic NB-IoT PHY functionalities are tested and overcome the challenges described.
References & Appendix

- 3GPP: 36.304 Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) procedures in idle mode
- 3GPP: 36.211 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation
- 3GPP: 36.213 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures

THANK YOU!!