Internet Engineering Task Force A. Ratilainen
Internet-Draft Ericsson
Intended status: Informational July 8, 2016
Expires: January 9, 2017

NB-IoT characteristics
draft-ratilainen-lpwan-nb-iot-00

Abstract

Low Power Wide Area Networks (LPWAN) are wireless technologies covering different Internet of Things (IoT) applications. The common characteristics for LPWANs are large coverage, low bandwidth, small data sizes and long battery life operation. One of these technologies include Narrowband Internet of Things (NB-IoT) developed and standardized by 3GPP. This document is an informational overview to NB-IoT and gives the principal characteristics and restrictions of this technology in order to help with the IETF work for providing IPv6 connectivity to NB-IoT along with other LPWANs.

Table of Contents

1. Introduction

The purpose of this document is to provide background information and typical link characteristics about NarrowBand Internet of Things (NB-IoT) to be considered in IETF's 6LPWA work.

NB-IoT is a Low Power Wide Area (LPWA) technology being standardized by the 3GPP. NB-IoT has been developed with the following objectives in mind:

- Improved indoor coverage

- Support of massive number of low throughput devices

- Low delay sensitivity

- Ultra-low device cost

- Low device power consumption

- Optimized network architecture

The standardization of NB-IoT was finalized with 3GPP Release-13 in June 2016, but further enhancements for NB-IoT are worked on in the following releases, for example in the form of multicast support. For more information of what has been specified for NB-IoT, 3GPP specification 36.300 [TGPP36300] provides an overview and overall description of the E-UTRAN radio interface protocol architecture, while specifications 36.321 [TGPP36321], 36.322 [TGPP36322], 36.323 [TGPP36323] and 36.331 [TGPP36331] give more detailed description of MAC, RLC, PDCP and RRC protocol layers respectively. The new versions of the specifications including NB-IoT are not yet available

due to novelty of the feature, but should be shortly available in the 3GPP website.

2. Overview of the NB-IoT technology

Machine type communication (MTC) refers to the emerging type of wireless communications where machine-like devices talk to each other through mobile networks or locally. Its requirements range from Massive MTC type of data with low cost, low energy consumption, small data volumes and massive numbers to critical MTC type of high reliability, very low latency and very high availability.

NB-IoT has been designed to satisfy a plethora of use cases and combination of these requirements, but especially NB-IoT targets the low-end Massive MTC scenario with following requirements: Less than 5$ module cost, extended coverage of 164 dB maximum coupling loss, battery life of over 10 years, ~55000 devices per cell and uplink reporting latency of less than 10 seconds.

NB-IoT supports Half Duplex FDD operation mode with 60 kbps peak rate in uplink and 30 kbps peak rate in downlink. Highest modulation scheme is QPSK in both uplink and downlink. As the name suggests, NB-IoT uses narrowbands with the bandwidth of 180 kHz in both, downlink and uplink. The multiple access scheme used in the downlink is OFDMA with 15 kHz sub-carrier spacing. On uplink multi-tone SC-FDMA is used with 15 kHz tone spacing or as a special case of SC-FDMA single tone with either 15kHz or 3.75 kHz tone spacing may be used. These schemes have been selected to reduce the User Equipment (UE) complexity.

NB-IoT can be deployed in three ways. In-band deployment means that the narrowband is multiplexed within normal LTE carrier. In Guard-band deployment the narrowband uses the unused resource blocks between two adjacent LTE carriers. Also standalone deployment is supported, where the narrowband can be located alone in dedicated spectrum, which makes it possible for example to refarm the GSM carrier at 850/900 MHz for NB-IoT. All three deployment modes are meant to be used in licensed bands. The maximum transmission power is either 20 or 23 dBm for uplink transmissions, while for downlink transmission the eNodeB may use higher transmission power, up to 46 dBm depending on the deployment.

For signaling optimization, two options are introduced in addition to legacy RRC connection setup, mandatory Data-over-NAS (Control Plane optimization, solution 2 in [TGPP23720]) and optional RRC Suspend/ Resume (User Plane optimization, solution 18 in [TGPP23720]). In the control plane optimization the data is sent over Non Access Stratum, directly from Mobility Management Entity (MME) in core network to the

UE without interaction from base station. This means there are no Access Stratum security or header compression, as the Access Stratum is bypassed, and only limited RRC procedures.

The RRC Suspend/Resume procedures reduce the signaling overhead required for UE state transition from Idle to Connected mode in order to have a user plane transaction with the network and back to Idle state by reducing the signaling messages required compared to legacy operation

With extended DRX the RRC Connected mode DRX cycle is up to 10.24 seconds and in RRC Idle the DRX cycle can be up to 3 hours.

To recap, the following is a list of the most important characteristics of NB-IoT:

- Narrowband operation (180 kHz bandwidth) in licensed bands, either in in-band, guard band or standalone operation mode

- Support for 1 Data Radio Bearer (DRB) is mandatory, 2 additional DRBs are optional

- Maximum peak rate is 60 kbps in UL and 30 kbps in DL

- No channel access restrictions (up to 100% duty cycle)

- The maximum size of PDCP SDU and PDCP control PDU is 1600 octets in NB-IoT

- Data over non-access stratum is supported

- With eDRX, DRX cycle is up to 10.24 seconds in connected mode and up to 3 hours in idle mode

3. System architecture

NB-IoT network architecture is based on the network architecture of legacy LTE, which is illustrated in Figure 1. It consists of core network, called Evolved Packet Core (EPC), Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and the User Equipment (UE). Next we take a look at the key components of EPC.

```
+--+
|UE| \              +------+      +------+
+--+  \             | MME  |------| HSS  |
       \          / +------+      +------+
+--+    \+-----+ /      |
|UE| ----| eNB |-       |
+--+    /+-----+ \      |
       /          \ +--------+
      /            \|        |    +------+     Service PDN
+--+ /              |  S-GW  |----| P-GW |---- e.g. Internet
|UE|                |        |    +------+
+--+                +--------+
```

Figure 1: 3GPP network architecture

Mobility Management Entity (MME) is responsible for handling the mobility of the UE. MME tasks include tracking and paging UEs, session management, choosing the Serving gateway for the UE during initial attachment and authenticating the user. At MME, the Non Access Stratum (NAS) signaling from the UE is terminated.

Serving Gateway (S-GW) routes and forwards the user data packets through the access network and acts as a mobility anchor for UEs during handover between base stations known as eNodeBs and also during handovers between other 3GPP technologies.

Packet Data Node Gateway (P-GW) works as an interface between 3GPP network and external networks.

Home Subscriber Server (HSS) contains user-related and subscription-related information. It is a database, which performs mobility management, session establishment support, user authentication and access authorization.

E-UTRAN consists of components of a single type, eNodeB. eNodeB is a base station, which controls the UEs in one or several cells.

The illustration of 3GPP radio protocol architecture can be seen from Figure 2.

```
+---------+                                        +---------+
| NAS     |----|-----------------------------|----| NAS     |
+---------+    |    +---------+---------+    |    +---------+
| RRC     |----|----| RRC     | S1-AP   |----|----| S1-AP   |
+---------+    |    +---------+---------+    |    +---------+
| PDCP    |----|----| PDCP    | SCTP    |----|----| SCTP    |
+---------+    |    +---------+---------+    |    +---------+
| RLC     |----|----| RLC     | IP      |----|----| IP      |
+---------+    |    +---------+---------+    |    +---------+
| MAC     |----|----| MAC     | L2      |----|----| L2      |
+---------+    |    +---------+---------+    |    +---------+
| PHY     |----|----| PHY     | PHY     |----|----| PHY     |
+---------+         +---------+---------+         +---------+
            LTE-Uu                         S1-MME
    UE                     eNodeB                      MME
```

Figure 2: 3GPP radio protocol architecture

The radio protocol architecture of NB-IoT (and LTE) is separated into control plane and user plane. Control plane consists of protocols which control the radio access bearers and the connection between the UE and the network. The highest layer of control plane is called Non-Access Stratum (NAS), which conveys the radio signaling between the UE and the EPC, passing transparently through radio network. It is responsible for authentication, security control, mobility management and bearer management.

Access Stratum (AS) is the functional layer below NAS, and in control plane it consists of Radio Resource Control protocol (RRC) [TGPP36331], which handles connection establishment and release functions, broadcast of system information, radio bearer establishment, reconfiguration and release. RRC configures the user and control planes according to the network status. There exists two RRC states, RRC_Idle or RRC_Connected, and RRC entity controls the switching between these states. In RRC_Idle, the network knows that the UE is present in the network and the UE can be reached in case of incoming call. In this state the UE monitors paging, performs cell measurements and cell selection and acquires system information. Also the UE can receive broadcast and multicast data, but it is not expected to transmit or receive singlecast data. In RRC_Connected the UE has a connection to the eNodeB, the network knows the UE location on cell level and the UE may receive and transmit singlecast data. RRC_Connected mode is established, when the UE is expected to be active in the network, to transmit or receive data. Connection is released, switching to RRC_Idle, when there is no traffic to save the UE battery and radio resources. However, a new feature was introduced for NB-IoT, as mentioned earlier, which allows data to be

transmitted from the MME directly to the UE, while the UE is in RRC_Idle transparently to the eNodeB.

Packet Data Convergence Protocol's (PDCP) [TGPP36323] main services in control plane are transfer of control plane data, ciphering and integrity protection.

Radio Link Control protocol (RLC) [TGPP36322] performs transfer of upper layer PDUs and optionally error correction with Automatic Repeat reQuest (ARQ), concatenation, segmentation and reassembly of RLC SDUs, in-sequence delivery of upper layer PDUs, duplicate detection, RLC SDU discard, RLC-re-establishment and protocol error detection and recovery.

Medium Access Control protocol (MAC) [TGPP36321] provides mapping between logical channels and transport channels, multiplexing of MAC SDUs, scheduling information reporting, error correction with HARQ, priority handling and transport format selection.

Physical layer [TGPP36201] provides data transport services to higher layers. These include error detection and indication to higher layers, FEC encoding, HARQ soft-combining. Rate matching and mapping of the transport channels onto physical channels, power weighting and modulation of physical channels, frequency and time synchronization and radio characteristics measurements.

User plane is responsible for transferring the user data through the Access Stratum. It interfaces with IP and consists of PDCP, which in user plane performs header compression using Robust Header Compression (RoHC), transfer of user plane data between eNodeB and UE, ciphering and integrity protection. Lower layers in user plane are similarly RLC, MAC and physical layer performing tasks mentioned above.

4. NB-IoT worst case performance

Here we consider the worst case scenario for NB-IoT. This scenario refers to the case with high coupling loss and the UE being the least capable. The link characteristics are listed assuming such conditions.

- 180 kHz bandwidth

- Uplink transmission

  * 1 Data Radio Bearer (DRB)

  * Single-tone transmission, 3.75 kHz spacing

o 164 dB maximum coupling loss (see Table 1

Numerology	3.75 kHz
(1) Transmit power (dBm)	23.0
(2) Thermal noise density (dBm/Hz)	-174
(3) Receiver noise figure (dB)	3
(4) Occupied channel bandwidth (Hz)	3750
(5) Effective noise power = (2) + (3) + 10*log ((4)) (dBm)	-135.3
(6) Required SINR (dB)	-5.7
(7) Receiver sensitivity = (5) + (6) (dBm)	-141.0
(8) Max coupling loss = (1) - (7) (dB)	164.0

Table 1: NB-IoT Link Budget

Under such conditions, NB-IoT may achieve data rate of roughly 200 bps.

For downlink with 164 dB coupling loss, NB-IoT may achieve higher data rates, depending on the deployment mode. Stand-alone operation may achieve the highest data rates, up to few kbps, while in-band and guard-band operations may reach several hundreds of bps. NB-IoT may even operate with higher maximum coupling loss than 170 dB with very low bit rates.

5. IANA Considerations

This memo includes no request to IANA.

6. Security Considerations

3GPP access security is specified in [TGPP33203].

7. Informative References

[TGPP23720]
3GPP, "TR 23.720 v13.0.0 - Study on architecture enhancements for Cellular Internet of Things", 2016.

[TGPP33203]
3GPP, "TS 33.203 v13.1.0 - 3G security; Access security for IP-based services", 2016.

[TGPP36201]
3GPP, "TS 36.201 v13.2.0 - Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description", 2016.

[TGPP36300]
3GPP, "TS 36.300 v13.4.0 (Available soon) - Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2", 2016.

[TGPP36321]
3GPP, "TS 36.321 v13.2.0 (Available soon) - Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification", 2016.

[TGPP36322]
3GPP, "TS 36.322 v13.2.0 (Available soon) - Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification", 2016.

[TGPP36323]
3GPP, "TS 36.323 v13.2.0 (Available soon) - Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification (Not yet available)", 2016.

[TGPP36331]
3GPP, "TS 36.331 v13.2.0 (Available soon) - Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification", 2016.

Author's Address

Antti Ratilainen
Ericsson
Hirsalantie 11
Jorvas 02420
Finland

Email: antti.ratilainen@ericsson.com