Random Access Preamble Detection for Narrowband IoT Systems

Technical Seminar

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Dec 2020

Abstract

Narrowband IoT (NB-IoT) is a low-power wide-area network (LPWAN) technology standard developed to provide improved coverage for massive number of low-throughput low-cost devices with low device power consumption in delay-tolerant applications. A new single tone signal with frequency hopping has been designed for NB-IoT Physical Random Access CHannel (NPRACH). When multiple uplink users attempt to attach simultaneously, the base station receives superimposed NPRACH preambles and must detect all users and acquire their synchronization parameters: time-of-arrival (ToA) and residual carrier frequency offset (RCFO). Here we discuss receiver techniques for user detection and estimation of ToA and RCFO for detected users.

Introduction

- The Internet of Things, or IoT, refers to the billions of physical devices around the world that are now connected to the internet, all collecting and sharing data.for example of IoT device can be a lightbulb that can be switched on using a smartphone app is an IoT device
- Long-distance low-rate MTC(Machine type communication) is ongoing area, and is applicable in scenarios such as meters, smart parking, smart agriculture and so on
- Low power wide area (LPWA) technologies is a promising solution for long range and low power Internet of Things (IoT) and machine type communication (MTC) applications. The LPWA networks have critical requirements for long battery life, extended coverage, high scalability, and low device and deployment costs.

Different wireless technologies

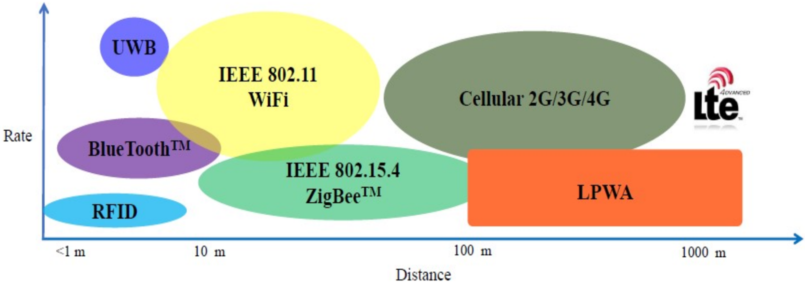

Figure: Coverage and transmission rate comparisons

Low Power Wide Area technologies

- The LPWA technologies can be cellular or non-cellular wireless technologies. The cellular technologies(which uses licensed spectrum) include
  1. LTE-M (LTE-machine type communication) which include eMTC(enhanced MTC),
  2. EC-GSM-IoT (Enhanced Coverage-GSM-IoT) and
  3. Narrowband Internet of Things (NB-IoT)
- whereas non-cellular technologies uses unlicensed spectrum,e.g:LoRa(Longe Range) and SigFox.
- **NB-IoT**: NB-IoT is a LPWA technology which was standardized by 3GPP in June,2016.The architecture of NB-IoT is extensively derived from legacy LTE. NB-IoT technology is appropriate for users transmitting low, infrequent, and delay-tolerant data.

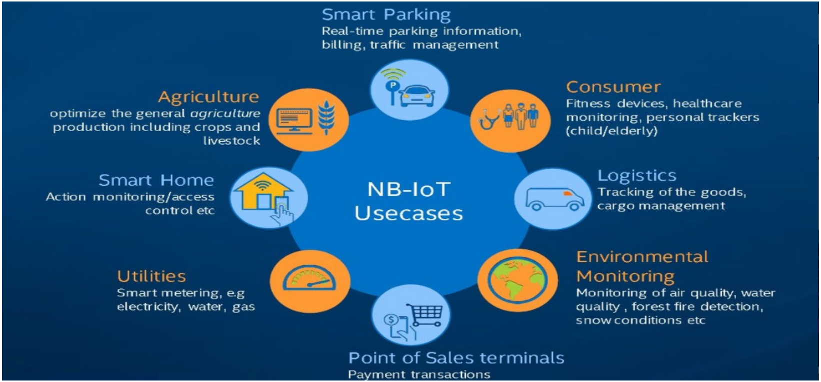

Figure: NB-IoT use cases

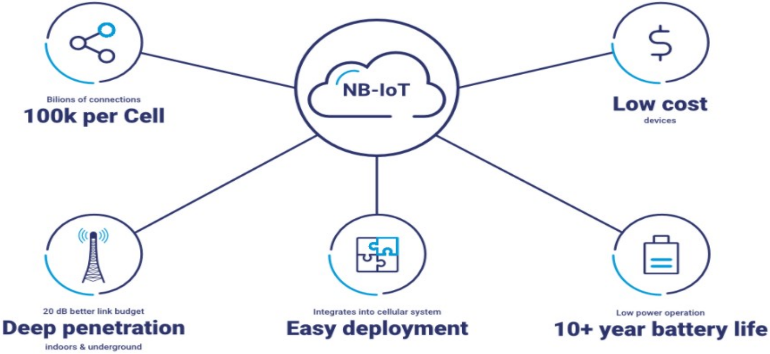

Figure: NB-IoT objectives

Deployment scenarios of NB-IoT

NB-IoT has a channel bandwidth of 200 kHz but occupies only 180 kHz. This is equal to one resource block in LTE (1 RB). With this selection, the following operation modes are possible:

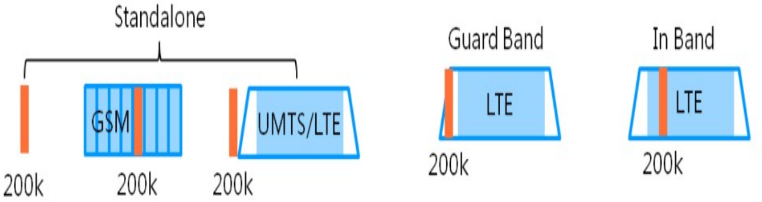

Figure: Deployment scenarios of NB-IoT

Downlink slot and Frame structure:

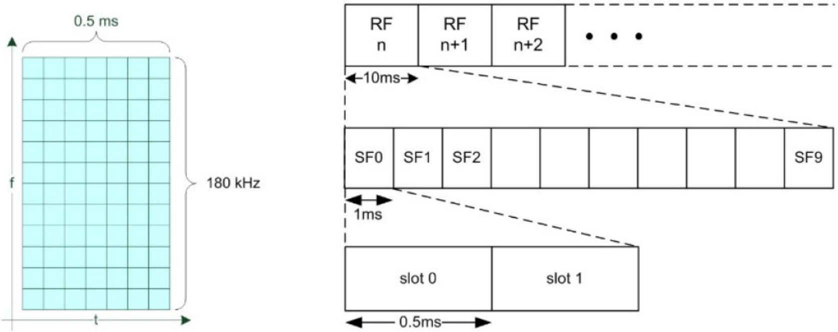

Figure: Downlink slot and frame structure

Physical layer in NB-IoT:Downlink

Physical channels and signals:

- NB-IoT defines three physical channels with the same designation as in LTE:
  1. NPBCH - Narrowband Physical Broadcast CHannel
  2. NPDCCH - Narrowband Physical Downlink Control CHannel
  3. NPDSCH - Narrowband Physical Downlink Shared CHannel
- As in LTE, NB-IoT provides the UE with Reference and synchronization signals in the downlink.
  1. NPSS - Narrowband Srimary Synchronization Signal
  2. NSSS - Narrowband Secondary Synchronization Signal
  3. NRS - Narrowband Reference Signal

Physical channels and signals:

- NB-IoT defines two physical channels and a demodulation reference signal (DMRS):
  1. NPUSCH - Narrowband Physical Uplink Channel.
  2. NPRACH - Narrowband Physical Random Access Channel.

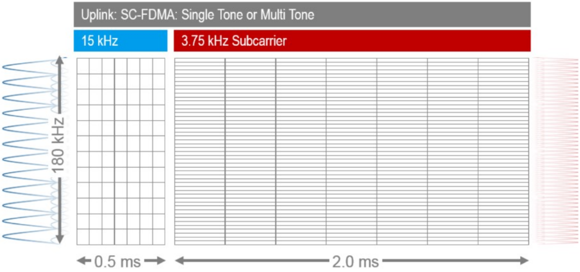

Figure: Resource element grid for one slot in the uplink.

Physical layer in NB-IoT:Uplink

NPUSCH format	Transport channel	Δf in kHz	Number of carriers	Number of slots	T^{slot} in ms	T^{RU} in ms
1	UL-SCH	3.75	1	16	2	32
		15	1	16	0.5	8
			3	8	0.5	4
			6	4	0.5	2
			12	2	0.5	1
2	UCI	3.75	1	4	2	8
		15	1	4	0.5	2

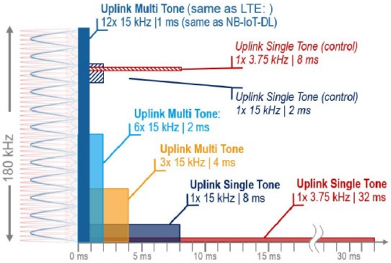

Figure: Overview of possible resource units(RU's).

Random access channel(NPRACH) I

- The Random Access Channel (NPRACH) uses a single tone with frequency hopping and 3.75 kHz subcarrier spacing.
- The preamble comprises of 4 symbol groups transmitted without gaps While each group uses a single subcarrier, it can hop across 12 subcarriers and each symbol group has a cyclic prefix(CP) followed by 5 symbols.
- Two preamble formats are defined, format 0 and format 1, which differ in their CP length. The CP length is 66.67s (format 0) for cell radius up to 10 km and 266.7s (format 1) for cell radius up to 40 km.

Random access channel(NPRACH) II

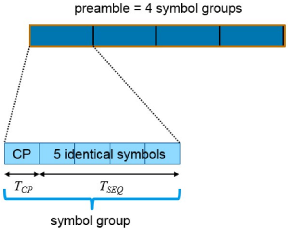

Figure: NPRACH Preamble.

- The frequency hopping algorithm is designed in a way that different selections of the first subcarrier lead to hopping schemes which never overlap.
- Hence there are as many different congestion free preambles as there are subcarrier allocated to the NPRACH.

Random access channel(NPRACH) III

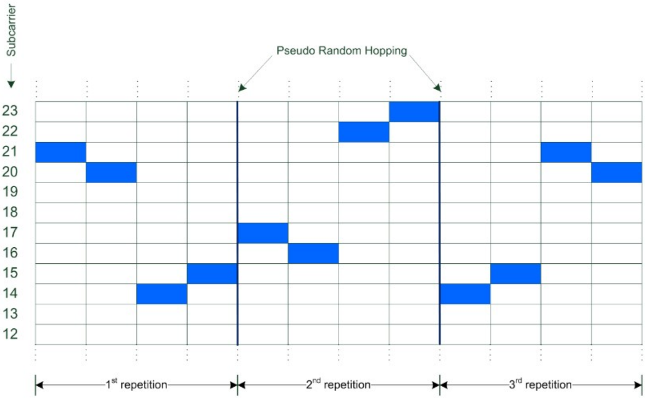

Figure: An illustration of NPRACH frequency hopping.

Preamble detection and estimation I

- Let N be the FFT size and N_{cp} be the number of cyclic prefix samples. Therefore a symbol group consists of $N_{cp} + \eta N$ samples($\eta = 5$).
- Let $u[m]_{m=0}^{L-1}$ denote the sequence of random access preamble.The baseband equivalent digital signal for the random access preamble transmission can be written as

$$s[n;m] = \frac{\sqrt{E}}{N} \sum_{k} S[k;m] e^{j2\pi \frac{k}{N} n}, \quad n = -N_{cp}, \ldots, N-1$$

- For each symbol group receiver discards first N_{cp} samples and performs FFT on remaining ηN samples. the $i-th$ received symbol in symbol group m is given by

$$\tilde{y}[i;m] = B(\Delta f, D) a[m] u[m] e^{j2\pi \Delta f (m(N_{cp}+\eta N)+iN)} e^{-j2\pi \frac{\Omega m}{N} D} + \tilde{v}[i;m].$$

$$B(\Delta f, D) = \sqrt{E} \frac{sin(N\pi\Delta f)}{Nsin(\pi\Delta f)} e^{j2\pi\Delta f(\frac{N-1}{2} - D)}$$

Preamble detection and estimation II

- Based on the received signal, The problem at the base station is to detect the presence of the active UEs and for each detected UE, estimate its ToA and CFO parameters accurately and efficiently.
- ToA and residual CFO can be jointly estimated as

$$
\begin{aligned}
(D^*, \Delta f^*) &= \arg\max_{D,\Delta f} J(D, \Delta f) \\
&= \arg\max_{D,\Delta f} \sum_{g=0}^{L/Q-1} |J_g(D, \Delta f)|^2
\end{aligned}
$$

where,

$$
J_g(D, \Delta f) = \sum_{m=gQ}^{(g+1)Q-1} \sum_{i=0}^{\eta-1} \tilde{y}[i; m] u^*[m] e^{-j2\pi \Delta f (m(N_c p + \eta N) + iN)} e^{j2\pi \frac{\Omega(m)}{N} D
$$

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Preamble detection and estimation III

- We can express the above equation in the form of 2D DTFT, as a result the search for $(D^*, \Delta f^*)$ is efficiently carried out using 2D FFT.i.e, we define

$$W_g[p,q] = \sum_{n=0}^{M_1-1} \sum_{k=0}^{M_2-1} w_g[n,k] e^{-j2\pi \frac{n}{M_1} p} e^{-j2\pi \frac{k}{M_2} q}$$

where,

$$w_g[n,k] = \begin{cases} z[i;m] & if n = (m - gQ)(\eta + 1) + i, k = \Omega(m); \\ 0 & \text{otherwise.} \end{cases}$$

$$z[i;m] = \tilde{y}[i;m] u^*[m].$$

Algorithm 1: NPRACH Detection: 2D FFT Method

Result: Residual Frequency Offset and Time-of-Arrival Estimation

y = Received Signal;
y = removeCP(y);
Y = FFT(Received Signal);
Z = Y * conj(U);
W = PickUserSpecificSpectralComponents(Z, Nsc);
J = FFT2(W, M1, M2);
(P, Q) = maxIndex(J);

if $P \geq \frac{M_1}{2}$ **then**

$$\Delta F = \frac{(P - M_1)}{N * M_1}$$

else

$$\Delta F = \frac{P}{N * M_1}$$

end

if $Q \geq \frac{M_2}{2}$ **then**

$$D = \frac{-(Q - M_2) * N}{M_2}$$

else

$$D = \frac{-Q * N}{M_2}$$

end

if $J[P, Q] \geq threshold$ **then**

$$UAD = 1$$

else

$$UAD = 0$$

end

Figure: Detection and estimation Algorithm.

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