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DECT NR+ Webinar Series

19 October 2023, 3 PM CEST

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DECT NR+ webinar series

- Welcome from the DECT Forum!
- Fourth webinar in the series about the DECT NR+ technology
- Today we cover the Physical Layer
- Speakers today:

Host Roel Ottink
DECT Forum

Heikki Berg
Nordic
Semiconductor

Some notes

- The presentations will take around 40 minutes
- Questions:
  - Can be asked by using the ‘Questions’ button in the bottom righthand corner
  - Will be answered after the presentations
  - If there are too many to answer in today’s webinar then they will be answered afterwards
- The webinar will be recorded and made available to all who have registered
- FAQ page: https://www.dect.org/news.aspx?id=390

Biography

Heikki Berg is Principal R&D Engineer at Nordic Semiconductor based in Tampere, Finland.

He received M.Sc. Degree from University of Oulu, Finland in 1998. He has 25+ year career in signal processing, application specific processing, and software. Heikki has been deeply involved in standardization and implementation some of the major radio standards from IS-136, GSM/EDGE, WiMAX, LTE, and LTE-Advanced to DECT-2020.

Heikki is the Rapporteur for the DECT-2020 Physical Layer and DECT-2020 Conformance Test Specification; Part I, Radio Transmission and Reception

DECT NR+ Physical Layer

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DECT NR+

Applications and use-cases

- Smart cities
- Smart homes and buildings
- Industrial IoT
- Professional audio applications

Features and benefits

- Licensed and license free operation
- Dedicated frequency band
- Self-healing and robust
- Range
- Mesh networking
- High density machine to machine communication
- Ultra low latency and reliablility

From classic DECT to NR+

Inherited

- 10 millisecond frame split into 24 slots, 416us each
- Channel raster of 0.864 MHz (=1.728/2 MHz)
- Evaluation of free time-frequency channel for spectrum access

New

- Resilience to multipath propagation due to OFDM based modulation
- Strong forward-error correcting code
- Link adaptation with hybrid-ARQ
  - Retransmissions virtually error free
- > 10 dB link budget improvement compared to classic DECT.

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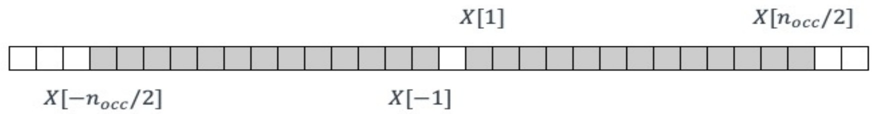
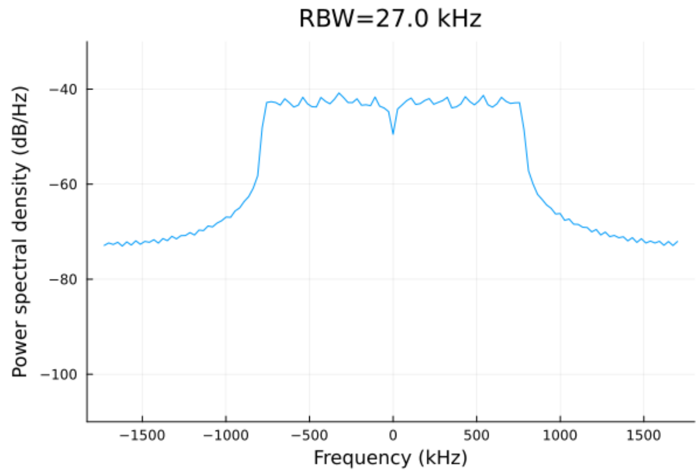
OFDM for radio link robustness

- Transmitted signal experiences multipath propagation in the wireless channel
  - Multiple delayed copies of transmitted signal arrive to the receiver and cause frequency selective fading
  - Causes destructive interference unless channel equalizer is implemented to combat the fading
- OFDM solves the multipath interference at system level by splitting the transmission into N orthogonal narrowband signals
- OFDM is the basis of many modern radio systems such as WIFI (IEEE 802.11a, g, n, ac, …), cellular 4G and 5G radio systems

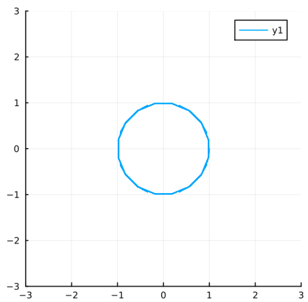
$$s[n] = \frac{1}{N} \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} X[k] e^{j2\pi \frac{k}{N} n}$$

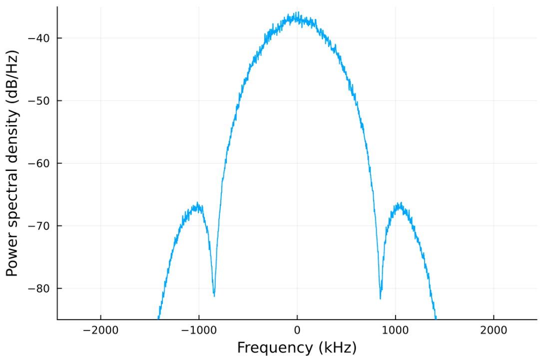




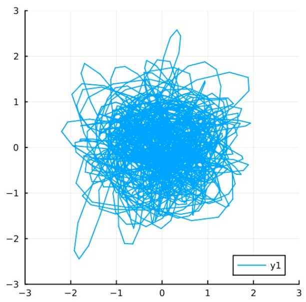
GMSK vs OFDM

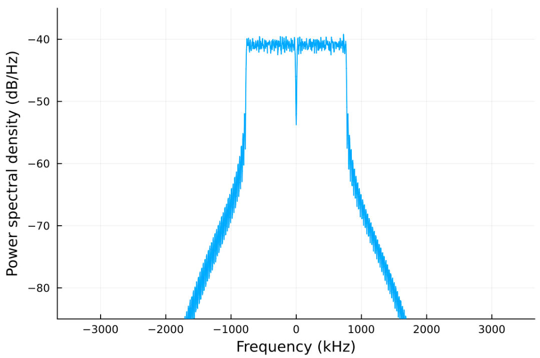
GMSK of classic DECT





OFDM





- GMSK modulation is constant envelope, the signal has peak-to-avarage power (PAPR) ratio of 0dB.
- OFDM signal can have PAPR of 10 dB
- Depicted transmissions have same mean transmission power of 21dBm

ITU-R 5G Approved RAT

- Scalable OFDM waveform with 1.728 MHz to 221.2 MHz nominal bandwidth
  - Subcarrier spacing **27**, 54, 108 and 216 kHz
  - Fourier transform scaling **64**, 128, 256, 512, 768, 1024
  - Occupied bandwidths from **1.536** MHz to 193.5 MHz
  - Up-to 8 MIMO streams
  - Subcarrier modulations are **BPSK, QPSK, 16-QAM**, 64-QAM, 256-QAM and 1024-QAM
  - Variable length packets from 0.5 to 16 slots (0,208ms to 6,67ms)

- 4 slot single antenna MCS-4 transmission with BW=1.728 MHz peak data rate 3.3 Mbit/s.
- 1 slot single antenna MCS 1-4 transmission every 10ms results 30-100 kbit/s.

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Link budget

Total Directional Peak EIRP	dBm	23,0
Nominal Channel Bandwidth	MHz	1,728
FFT Size		64
Subcarriers (including empty DC)		57
Subcarrier Spacing	Hz	27000
Occupied Channel Bandwidth	MHz	1,539
Cyclic prefix		0,125
Symbol Period	usec	41,67
Noise Figure	dB	5
Thermal Noise Floor	dBm/Hz	-173,93
Required SNR	dB	3,5
Noise Floor	dBm/Hz	-168,93
Noise Power	dBm	-106,56
Receiver Sensitivity	dBm	-103,1
Link Budget	**dB**	**126,1**

- Free space LOS > 25 km
- ITU-R M.2412 LOS > 2.5 km

Transmitter 5m from lake surface

Receiver 1.8m from lake surface

Measured LOS 6.2km (MCS1)

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Link budget

Total Directional Peak EIRP	dBm	23,0
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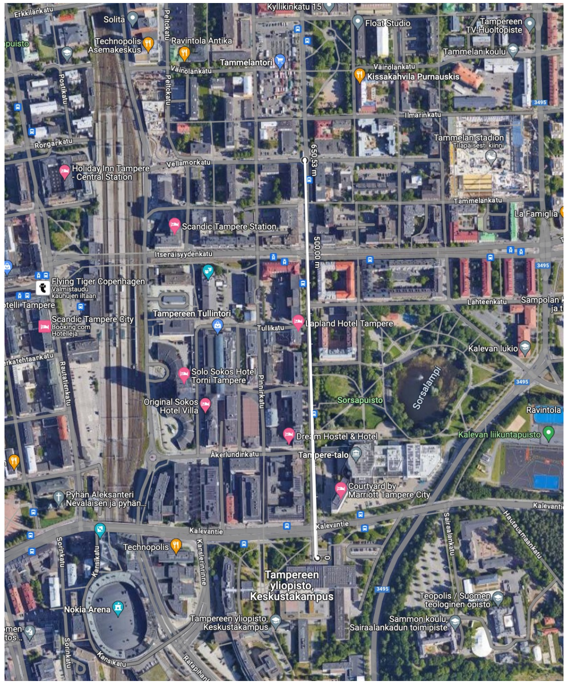


Measured Urban City 650m (MCS1)

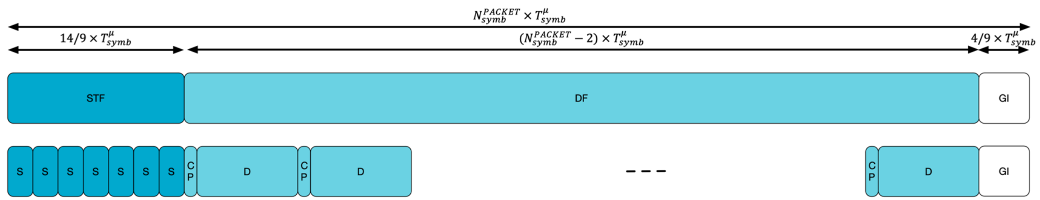
Transmitter 1.8m from ground

Receiver 1.8m from ground

Measured LOS 6.2km (MCS1)

Transmission packet structure

- DECT NR+ transmission packet consists of synchronization training field, data field and guard interval.
- Data field carries demodulation reference signal, physical control channel and physical data channel.
- Packet length signaled in the fixed size physical control channel in the first 2 OFDM symbols



Physical control channel (PCC) encoding

- Number of physical control channel payload bits is either 40 or 80
- Physical control channel is always transmitted using 98 subcarriers
- The receiver may need to blind decode both payload bit sizes and select the one with CRC match
- PCC of any transmission can be decoded by any recipient
  - Originating network, transmitter, recipient, transmission power can be used in interference coordination

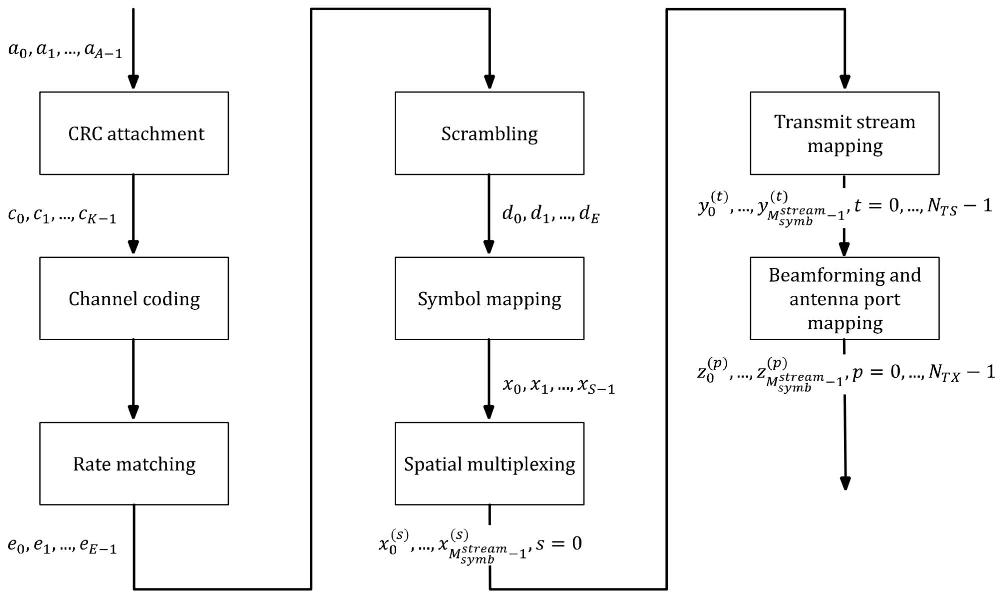


Figure 7.5.1-1: Physical control channel encoding

Physical data channel (PDC) encoding

- Clause 5.3 specifies the algorithm for calculating the transport block size using
  - Number of subcarriers available for transmission for given packet length
  - Modulation and coding scheme
  - Number of spatial streams
  - Maximum turbo encoder block size for given radio device class

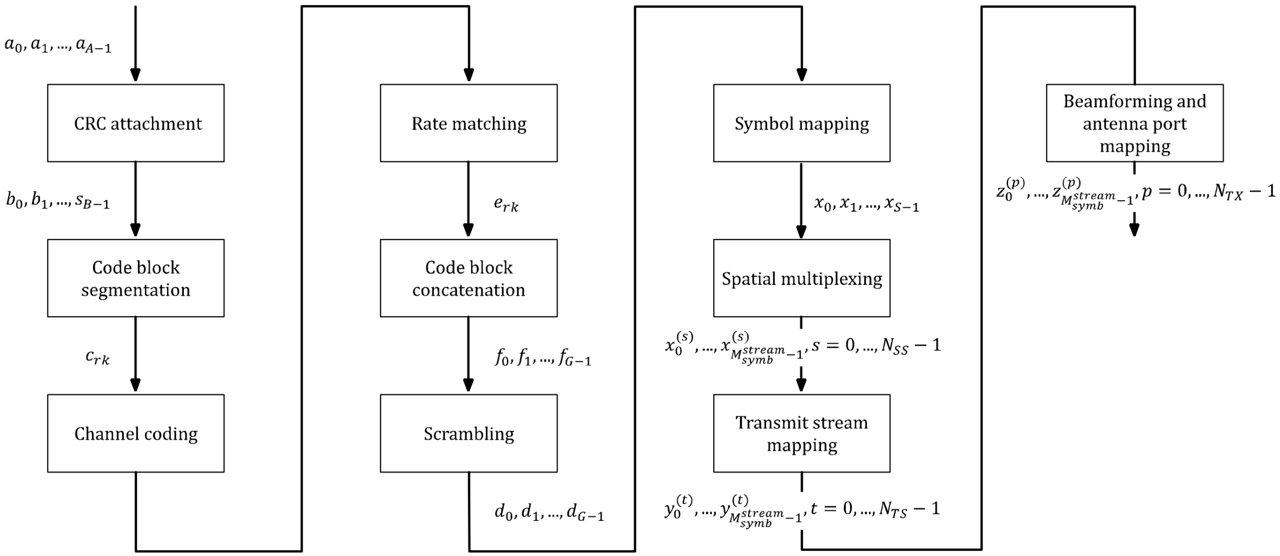
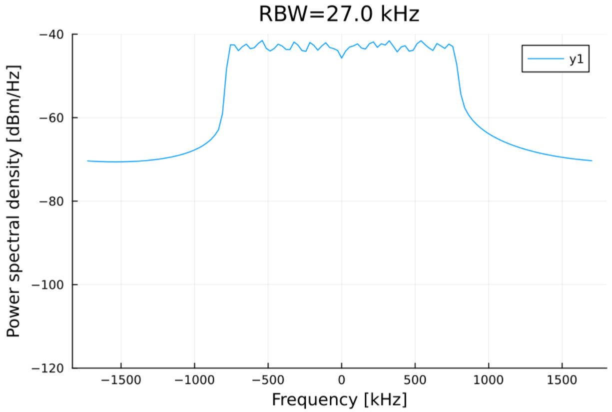


Figure 7.6.1-1: Physical Data Channel Encoding

Signal transmission



Signal of transmission power 19dBm analyzed with

Welch periodogram using a kaiser(n_fft, α=2.5) window

For each symbol l the time domain symbol s of length $N = N_{FFT} + N_{CP}$ is defined as

$$s[n,l] = \frac{1}{N_{FFT}} \sum_{k=0}^{N_{FFT}-1} S[k,l] e^{j\frac{2\pi k(n-N_{CP})}{N_{FFT}}}, \quad n = 0,\ldots,N-1, \tag{1}$$

where N_{FFT} is the fourier transform size and N_{CP} is the cyclic prefix length, k is the subcarrier index, n is the sample time indes and l is the symbol index.

The equation (1) can be further developed to

$$s[n] = \frac{1}{N_{FFT}} \sum_{k=0}^{N_{FFT}-1} \sum_{l=-\infty}^{\infty} S[k,l] p[n-lN] e^{j\frac{2\pi k(n-N_{CP}-lN)}{N_{FFT}}}, \quad n = 0,\ldots,\infty, \tag{2}$$

where rectangular pulse shape $p[n]$ is defined as:

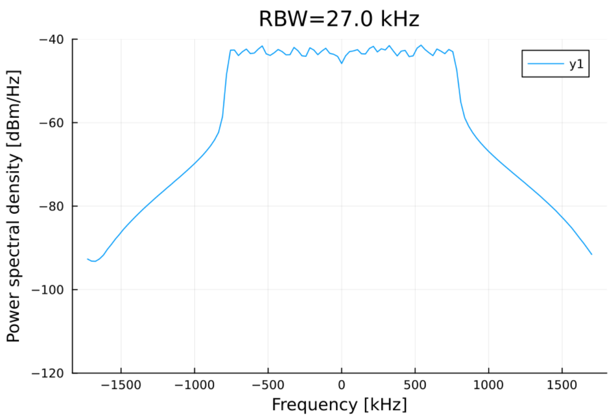
$$p[n] = \begin{cases} 1, & n = 0,\ldots,N-1 \\ 0, & otherwise \end{cases} \tag{3}$$

Signal transmission, WOLA

Windowed overlapped OFDM is defined in [BJR13] by changing the rectangular pulse shape of equation (2) to smoothly converging pulse shape on the two sides and 1.0 in the middle.This windowing decreases the sidelobe energy.

Any pulse shape where in roll-off portions of the pulse satisfy condition $f[i] + f[\beta N - i - 1] = 1$ can be used. With this condition the combined energy of overlapping pulses is 1.0. The pulse is defined as follows:

$$p[n] = \left\{ \begin{array}{rl} f[n], & 0 \leq n < \beta N \\ 1, & \beta N \leq n < N \\ f[\beta N - 1 - (n - N)], & N \leq n < (\beta + 1)N - 1 \\ 0, & otherwise \end{array} \right\} \quad (4)$$



Signal of transmission power 19dBm analyzed with Welch periodogram using a kaiser(n_fft, α=2.5) window

Raised cosine WOLA of 3 samples

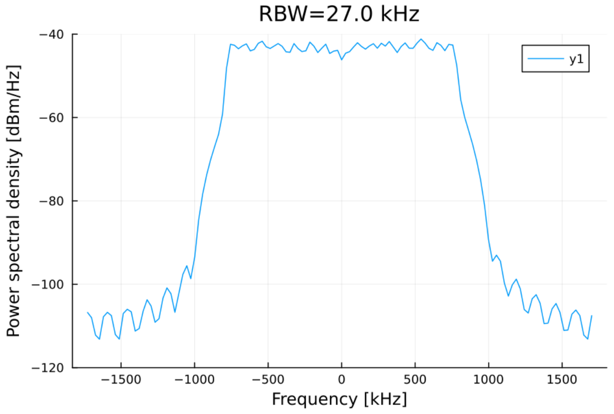
[BJR13] Erdem Bala, Li Jialing, and Yang Rui. Shaping spectral leakage. IEEE Vehicular Technology Magazine, Sept 2013.

Signal transmission, filtered OFDM

Pulse shaping can be applied to the time domain OFDM signal of (2) by convolving the signal $s[n]$ with appropriate impuse pulse response $h[k],\ k = 0, \dots, K-1$

$$y[n] = \sum_{k=0}^{K-1} s[n-k]h[k], \quad n = 0, \dots, \infty, \tag{5}$$

where $s[n] = 0, \forall\, n < 0$.



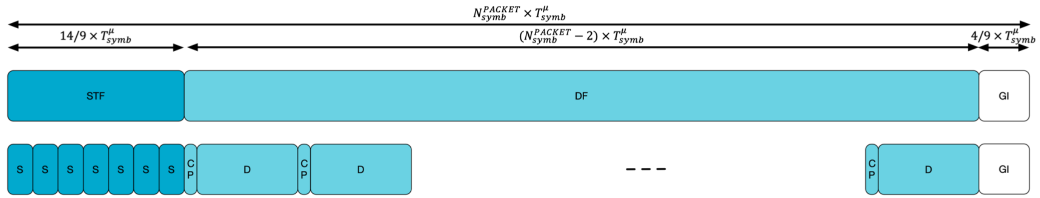
Signal of transmission power 19dBm analyzed with Welch periodogram using a kaiser(n_fft, α=2.5) window

Transmit filter impulse response square root raised cosine with roll-off 0.125

Synchronization training field (STF)

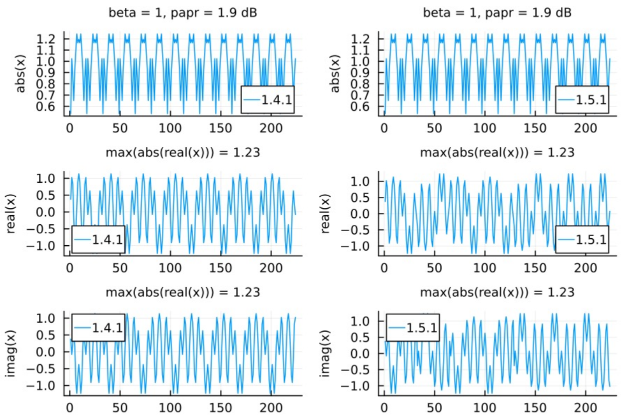
$$k_{STF} = -N_{occ}/2, \dots, -4, 4, \dots, N_{occ}/2$$

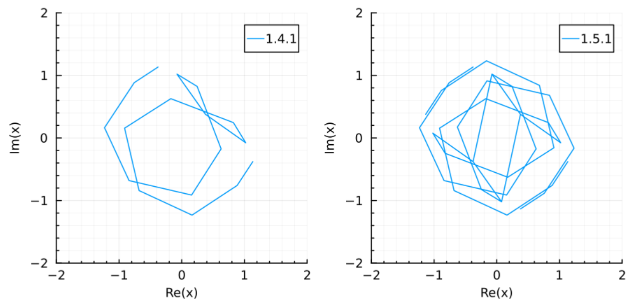
$$s_{\beta=1} = e^{\frac{j\pi}{4}} \cdot [1, -1, 1, 1, -1, 1, 1, -1, 1, 1, 1, -1, -1, -1]^T$$



$$S_{STF} = \mathbf{0}_{N_{fft}\times 1}$$
$$S_{STF}[k_{STF}] = 2.0 \cdot s_\beta$$

$$s_{STF} = \mathbf{1}_{N_{rep}\times 1} \otimes (N_{fft}/\sqrt{N_{OCC}} \cdot IFFT(S_{STF})[0 : N_{fft}/4 - 1])$$





$$\mathbf{c} = [1, -1, 1, 1, -1, -1, -1], \ \mu = 1$$
$$\mathbf{c} = [1, -1, 1, 1, 1, -1, -1, -1, -1, -1], \ \mu = 2, 4, 8$$

$$S_{STF} = \mathbf{0}_{N_{fft}\times 1}$$
$$S_{STF}[k_{STF}] = 2.0 \cdot s_\beta$$

$$s_{STF} = \mathbf{c} \otimes (N_{fft}/\sqrt{N_{OCC}} \cdot IFFT(S_{STF})[0 : N_{fft}/4 - 1])$$

Autocorrelation based time & frequency synchronization

$$\psi(m) = \frac{\gamma(m)}{\phi(m)}$$

$$\gamma(m) = \sum_{k=0}^{N-1} r(m+k) r^*(m+k+Q) u(\lfloor \frac{k}{Q} \rfloor)$$

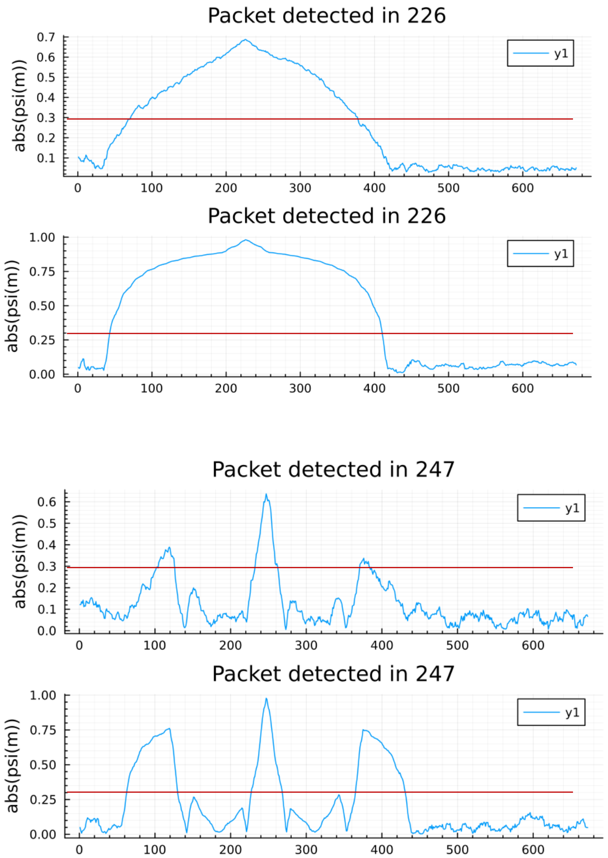
$$\phi(m) = \frac{1}{2} \sum_{k=0}^{N-1} \left(|r(m+k)|^2 + |r(m+k+Q)|^2 \right)$$

$$u(p) = c(p) \cdot c(p+1),\ p = 0, \ldots, P-2,$$

Define $S = \{m \mid |\psi(m)| > \rho\}$

$$\lambda(m) = \arg\max_{m \in S} |\psi(m)|$$

$$\hat{f}_{err} = \frac{\angle\gamma(m)}{2 * \pi} \cdot \frac{fs}{Q}$$



- Autocorrelation based time synchronization is depicted in the four figures.
- Topmost pair without STF cover sequence (6dB and 20dB SNR)
- Lowermost pair with STF cover sequence (6dB and 20dB SNR)

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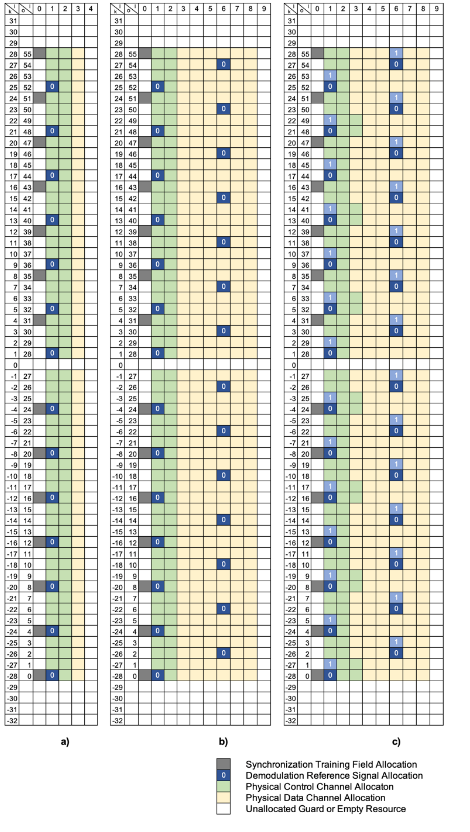
Channel estimation

- Channel estimation from each transmitter to each receiver antenna is based on known demodulation reference symbols
- For 1 and 2 antenna transmissions DRS pattern repeats every 5 OFDM symbols and for 4 and 8 antenna transmissions every 10 OFDM symbols

$$\tilde{\mathbf{h}} = \mathbf{r} \oslash \mathbf{d} = \mathbf{r} \odot \mathrm{conj}(\mathbf{d})$$

$$\tilde{\mathbf{h}}_W = \mathbf{W} \cdot \tilde{\mathbf{h}}$$

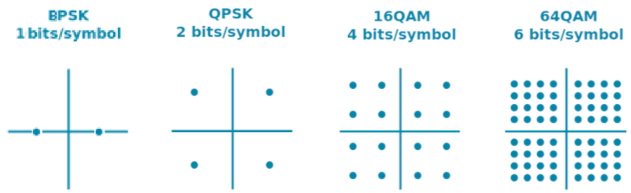


Modulation & Demodulation

- **Physical Data Channel (PDC) modulation**

  BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM, 1024-QAM

  - With “turbo coding rates”: ½, 2/3, 3/4, 5/6



$$\mathbf{r}(f,k) = \begin{bmatrix} r_0(f,k) \\ r_1(f,k) \\ \vdots \\ r_{N-1}(f,k) \end{bmatrix} = \begin{bmatrix} c_0(f,k) \\ c_1(f,k) \\ \vdots \\ c_{N-1}(f,k) \end{bmatrix} b(f,k) + \begin{bmatrix} n_0(f,k) \\ n_1(f,k) \\ \vdots \\ n_{N-1}(f,k) \end{bmatrix}$$

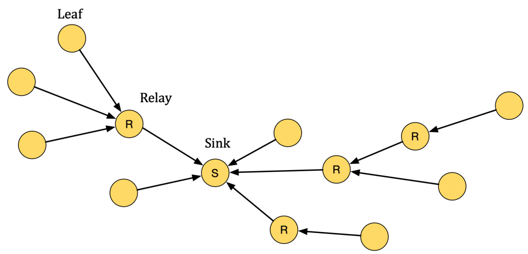
$$\mathbf{r} = \mathbf{c}b + \mathbf{n},$$

$$max_b \left\{ \frac{1}{\pi^N \mid \mathbf{R_{nn}} \mid} exp\left(-\left(\mathbf{r} - \mathbf{c}b\right)^H \mathbf{R_{nn}^{-1}} \left(\mathbf{r} - \mathbf{c}b\right) \right) \right\},$$

$$LLR_{b(f,k)}(d_i) = ln\left(\frac{Pr(d_i = 1, \mathbf{r})}{Pr(d_i = 0, \mathbf{r})} \right)$$

ARQ

- ARQ - Automatic repeat request
  - Just resend the failed packet
- Chase combining Hybrid ARQ
  - Just resend the failed packet.
  - Receiver stores the soft-information of the failed decoding
- Incremental redundancy Hybrid ARQ
  - Resend but with additional redundancy
  - Receiver stores the soft-information of the failed decoding



- Receiver needs to keep track of the open HARQ processes per user.
- Memory requirement is linearly dependent on maximum TBS, number of processes per user, number of simultaneously active users.
- As users do not usually transmit same sized packets, dynamic memory management would decrease the memory requirements but is difficult to manage.

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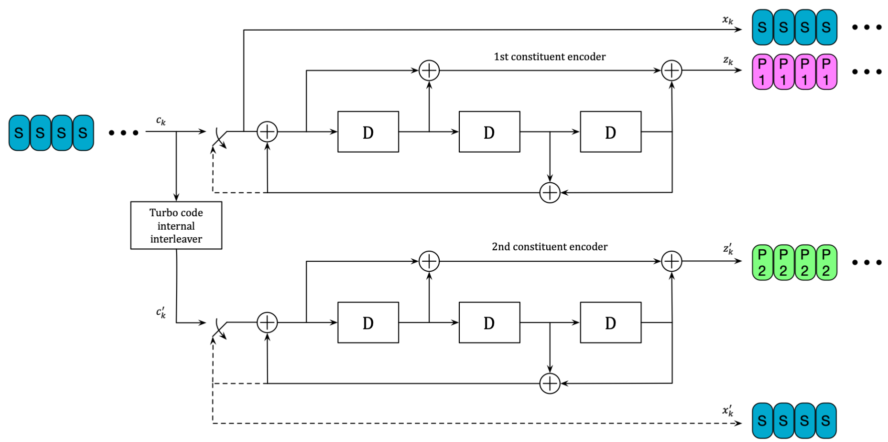
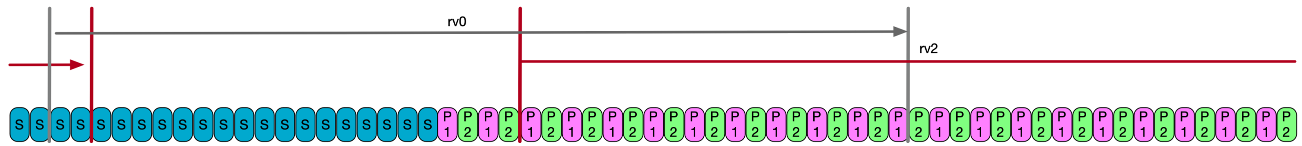
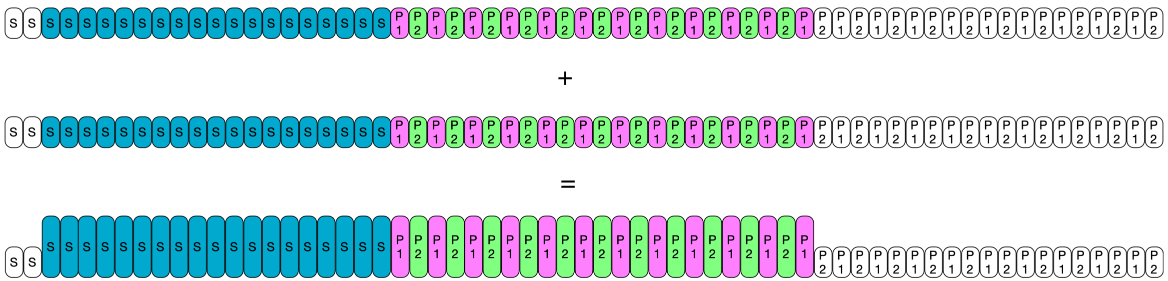
Forward error coding & hybrid ARQ

- Rate 1/3 parallel concatenated convolutional encoder
- Typically simpler and faster to decode than constraint length 7 convolutional code.
  - N * 2^7 > N * 2*2^3 + N
- Rate matcher selects the appropriate number of bits for transmission according to selected redundancy version



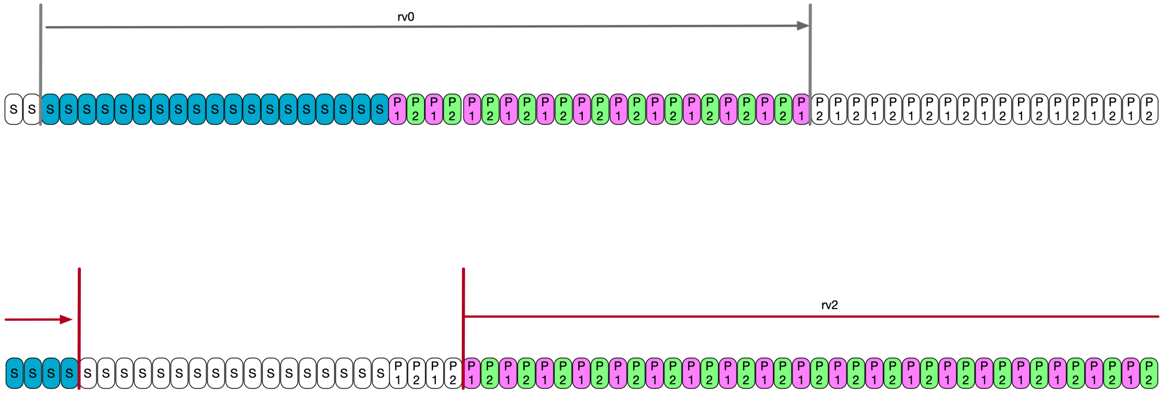


Chase combining Hybrid ARQ



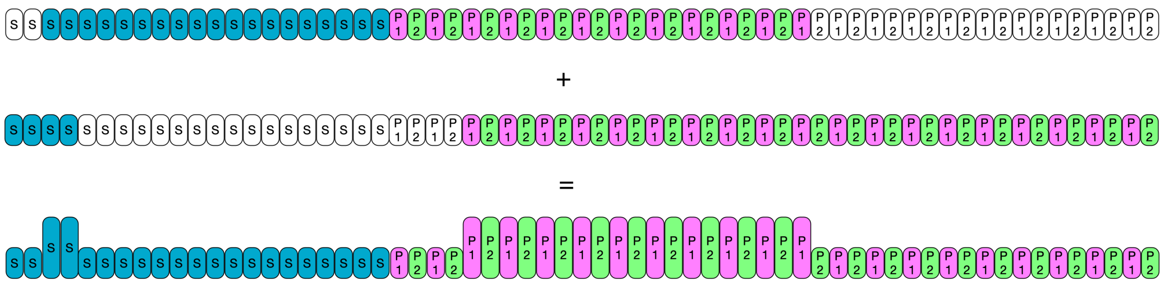
- Chase combining HARQ is NOT used in DECT NR+
- 3dB gain from single retransmission if transmission conditions remain the same

Incremental redundancy Hybrid ARQ



- Rate matcher selects the appropriate number of bits for transmission according to selected redundancy version
- In this example we have 1/3 mother code and puncturing to 1/2 code rate.
  - Redundancy version 0 transmits most of the systematic bits and approximately half of the redundancy information
  - Redundancy version 2 transmits most of the redundancy and very little systematic bits

Incremental redundancy Hybrid ARQ



- Rate dematcher implements soft combining
  - When initial transmission with redundancy version 0 fails, receiver saves the soft information.
  - Additional redundancy is added to the previously saved soft information
- Coding rate improvement and some bits get energy gain
  - ~5dB gain compared to initial transmission in static conditions

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Link adaptation

- Transmission power of each transmission known
- Reciprocal pathloss can be assumed
- MCS adaptation
- Incremental redundancy retransmissions

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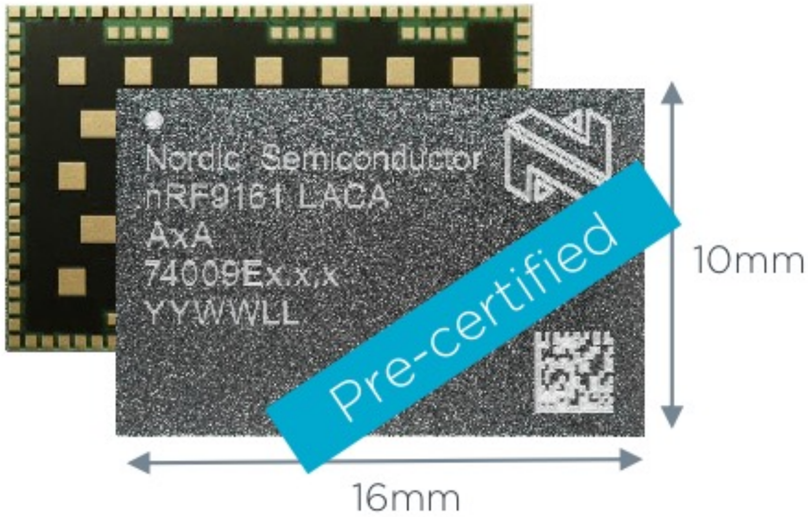
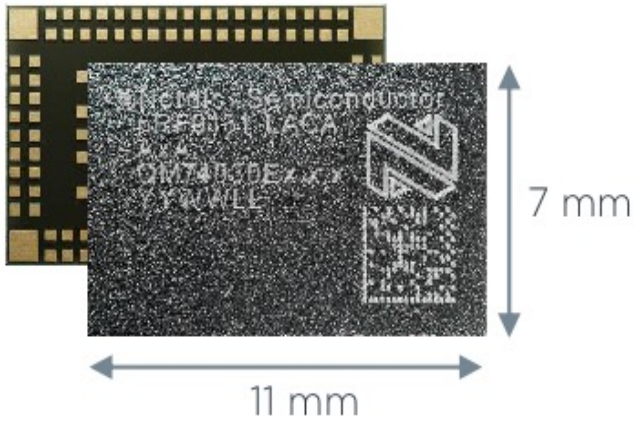
The Integrated Nordic SiP Products



nRF9161 SiP



nRF9131 mini-SiP

Simplified supply chain, lower total cost

LTE-M NB-IoT GNSS

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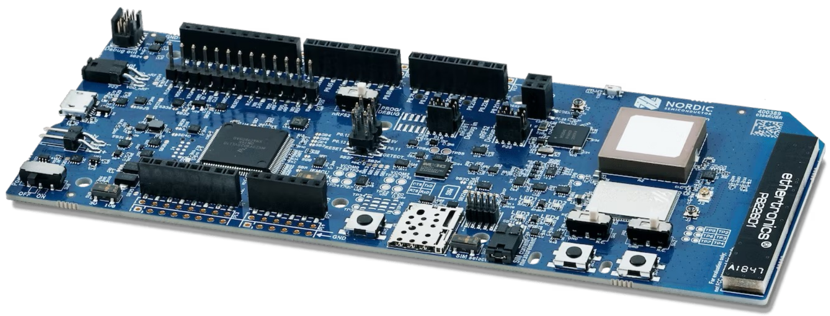
nRF9161 DevKit



- SEGGER J-Link OB Debugger with debug out support
- UART interface through VCOM port
- USB connection for debug/programming and power

- Arduino Uno form factor extension
- Supports Bluetooth LE
- 4 LEDs user-programmable
- 2 buttons user-programmable
- 2 switches user-programmable

Topics in the webinar series

	Topics	Dates
#1	Introduction to NR+ and DECT Forum	20 April
#2	Applications and use cases	15 June
#3	The technology (upper layers)	26 September
#4	The technology (lower layers)	19 October
#5	How to get started with NR+	9 November
#6	Recap and panel discussion	9 November

DECT NR+ webinar series

- The last 2 webinars will be held on 9th November during the second day of the DECT World event
- We hope you enjoyed this webinar!
- Be part of shaping the NR+ journey and join us at the DECT Forum! https://www.dect.org/application-for-membership.aspx
- Or contact roel.ottink@dect.org for information
- Question time

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