OFDM Signal Navigation

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Agenda

- Introduction
- Mobile user requirements on navigation system
- OFDM modulation
- Ranging theory
  - Snapshoot navigation
  - DLL tracking
- Candidate Systems
- DVB-T signal experiment
- Conclusions

Mobile User Requirements on Navigation System

- High precision
- Navigation in indoor environment

Problem with GNSS signal availability

Large number of communication and broadcasting signals available

Communication systems

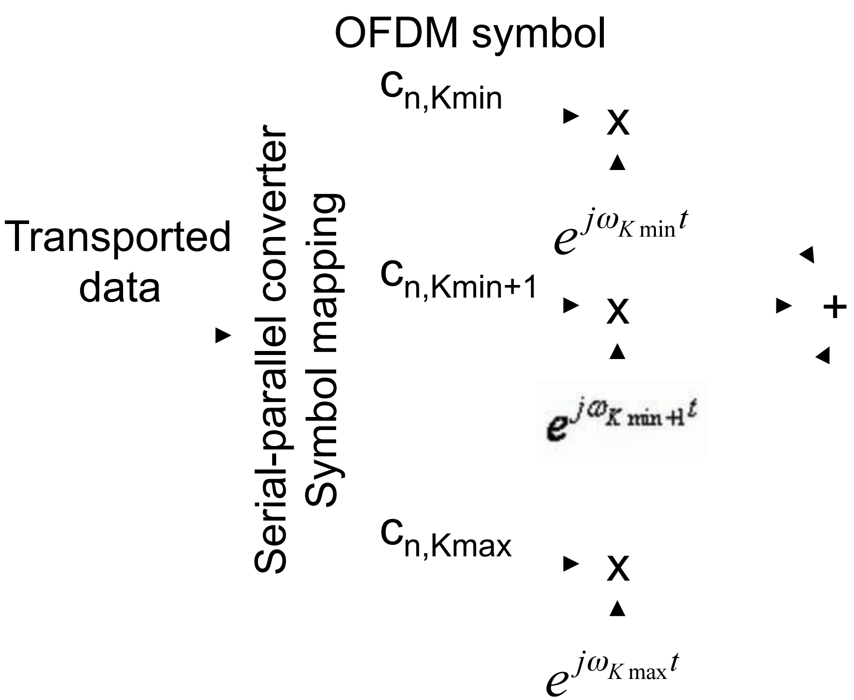
- Available at the densely populated areas
- OFDM modulation schema
  - Low sensitivity on radio channel quality
  - Relatively simple channel equalization and data demodulation
  - Single frequency network support

=>

Good modulation for broadcasting and communication systems

OFDM - Orthogonal Frequency Division Multiplex

- OFDM - Orthogonal Frequency Division Multiplex
  - Transported data are separated into large number of sub-streams
  - Sub-streams are modulated on particular carriers by QPSK, 16QAM, 64QAM, etc.
  - Carriers are orthogonal on symbol of duration T_U



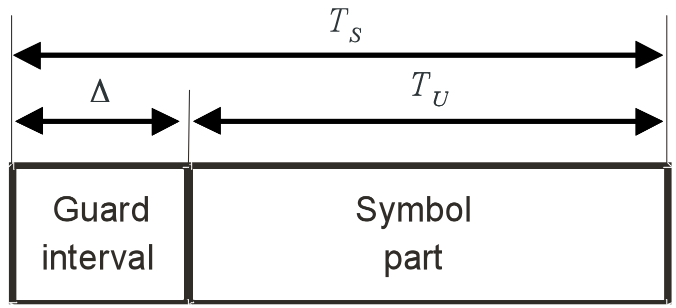
$$\tilde{s}_{OFDM}(t) = \sum_{n=-\infty}^{\infty} \sum_{k=K\min}^{K\max} c_{n,k} e^{j\omega_k t}$$

K_{min} – sequential number of first carrier

K_{max} – sequential number of last carrier

OFDM DVB-T Features

- Selective fading resistance
- Guard interval Δ
  - Multipath elimination
  - Single frequency network support
- OFDM symbol duration 100 - 1000 μs
- High E_b/N_0



Δ - guard interval
T_U - coherent part
T_s - OFDM symbol duration

$$s_{DVB}(t) = s_d(t) + s_{sp}(t) + s_{cp}(t) + s_{TPS}(t)$$

$s_d(t)$ Transmitted data carriers

$s_{sp}(t)$ Scattered pilot carriers

$s_{cp}(t)$ Continual pilot carriers

$s_{TPS}(t)$ TPS carriers

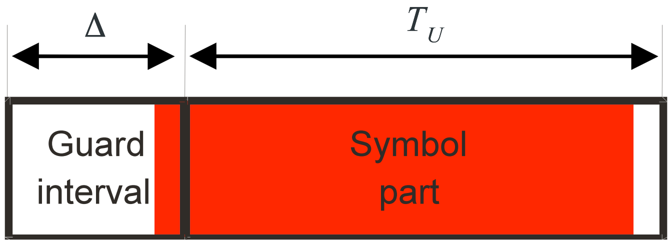
Candidate Systems

System	Frequency	Bandwidth	Range
DVB-T(H)	VHF, UHF	5-8 MHz	Medium
DRM	LF, MF, HF	4.5-20 kHz	Long
DAB	VHF, L	1.5 MHz	Medium
WiFi	2.4 or 5 GHz	20 MHz	Short
Imax	10 – 66 GHz	1-28 MHz	Short
4G			

Ranging Theory

- Snapshoot navigation
- DLL tracking

Snapshoot navigation



$$s_{DVB}(t) = s_d(t) + s_{sp}(t) + s_{cp}(t) + s_{TPS}(t)$$

- $s_d(t)$ — Transmitted data carriers
- $s_{sp}(t)$ — Scattered pilot carriers
- $s_{cp}(t)$ — Continual pilot carriers
- $s_{TPS}(t)$ — TPS carriers

Signal snapshot processing

Range Measurement Error

- Standard deviation of range measurement in AWGN

$$\left(\sigma_r^2\right)_{MIN} = \frac{c}{2} \cdot \frac{N_0}{2E\beta^2}$$

2β - signal effective bandwidth

$$\beta^2 = \frac{4\pi^2}{2E} \int_{-\infty}^{\infty} f^2 \left|\tilde{S}(f)\right|^2 df$$

E - signal energy

N_0 - spectral power density of the noise

$S(f)$ - spectral energy density of the processed signal

Carrier and power allocation of the DVB-T signal

$$s_{DVB}(t) = s_d(t) + s_{sp}(t) + s_{cp}(t) + s_{TPS}(t)$$

	Mode			
	2K		8K	
	No	Power	No	Power
scattered pilot carriers	143	13.7% boosted (16/9)	569	13.7% boosted (16/9)
continual pilot carriers	45	4.3% boosted (16/9)	177	4.3% boosted (16/9)
TPS carriers	17	0.9% normal (1)	68	0.9% normal (1)
data carriers	1500	81.1% normal (1)	6003	81.1% normal (1)
Total	1705	100 %	6817	100%

DVB-T 8K Signal Range Measurement Error

$$s_{DVB}(t) = s_d(t) + s_{sp}(t) + s_{cp}(t) + s_{TPS}(t)$$

100% of signal power

SNR [dB]	Continual pilot carriers σ_r [m]	Scatter & Continual pilot carriers σ_r [m]	Complete signal σ_r [m]
5	0.487	0.425	0.180
10	0.274	0.239	0.101
15	0.144	0.126	0.053
20	0.086	0.075	0.032
25	0.048	0.042	0.018
30	0.028	0.025	0.010

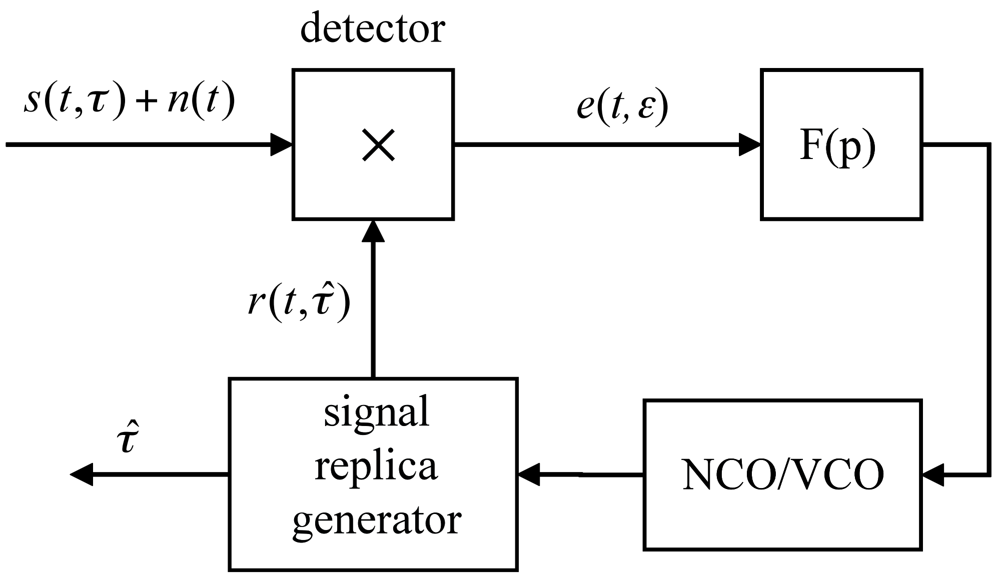
DVB-T Range Error

SNR [dB]	Theory σ_r [m]	Simulation σ_r [m]	Measurement σ_r [m]
5	0.487	0.422	0.494
10	0.274	0.224	0.286
15	0.144	0.134	0.168
20	0.086	0.079	0.105
25	0.048	0.046	0.92
30	0.028	0.031	0.83

Data demodulation

Ranging

OFDM Tracking

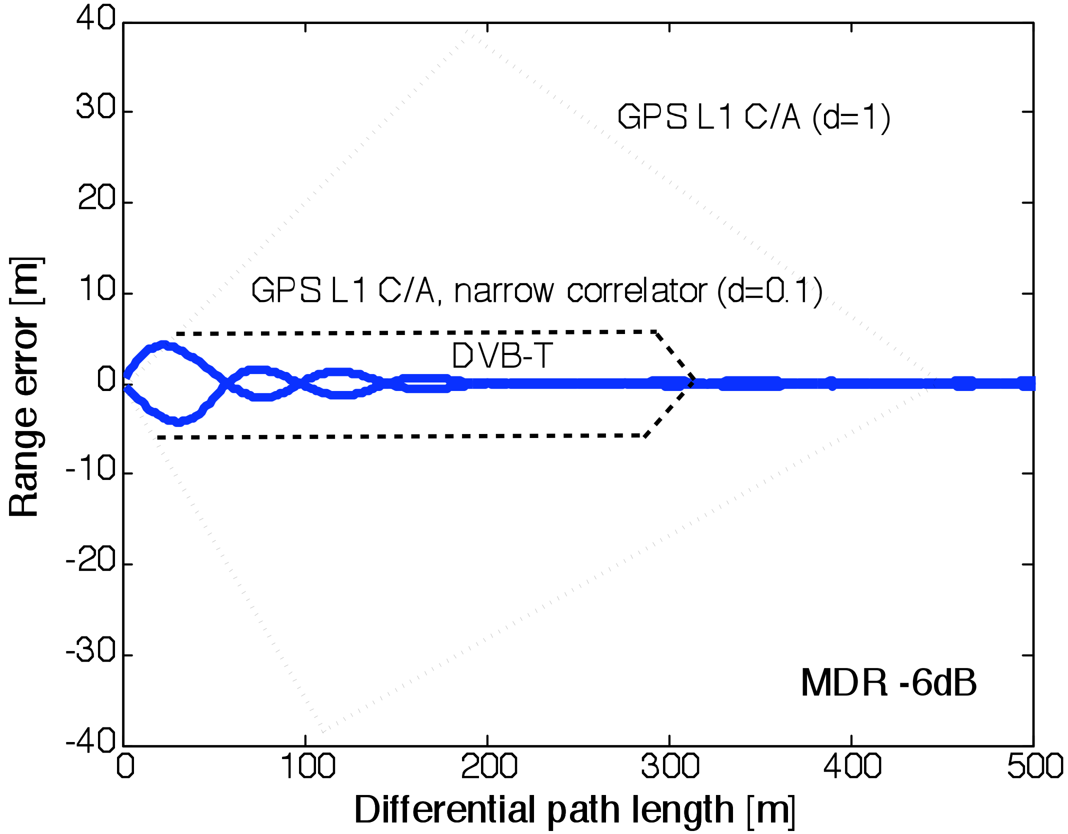


Range measurement error of DLL
(derived from linearized model)

$$\mathrm{var}[\varepsilon] = \frac{1}{2\pi}\int_{-\infty}^{\infty} C_\tau(j\omega)\left|1-H(j\omega)\right|^2 d\omega + 2C_\xi(0)B_n$$

Multipath Sensitivity of DVB-T

Multipath - main source of errors in ToA and DToA navigation systems



MDR – Multipath signal to Direct signal Ratio

DVB-T Navigation Receiver Concept
Preliminary Experiments

OFDM demod. & FEC decod.

Demultiplex.

Navigation message

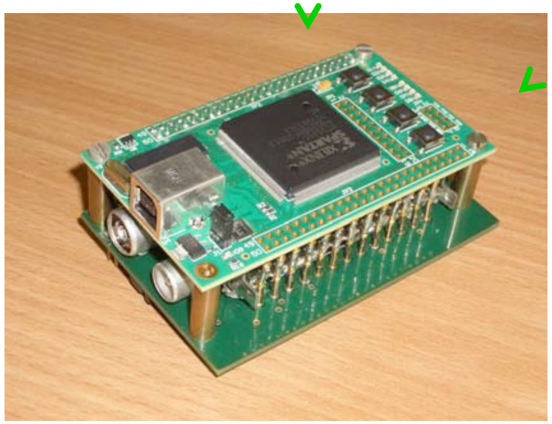
DVB-T tuner

Nav. computer

Snapshot acquisition

Snapshot processing

Pseudorange



USB

• Snapshot duration	2 ms
• Acquisition period	100 ms
• Frequency tuning	500 ms

DVB-T Range Error

SNR [dB]	Theory σ_r [m]	Simulation σ_r [m]	Measurement σ_r [m]
5	0.487	0.422	0.494
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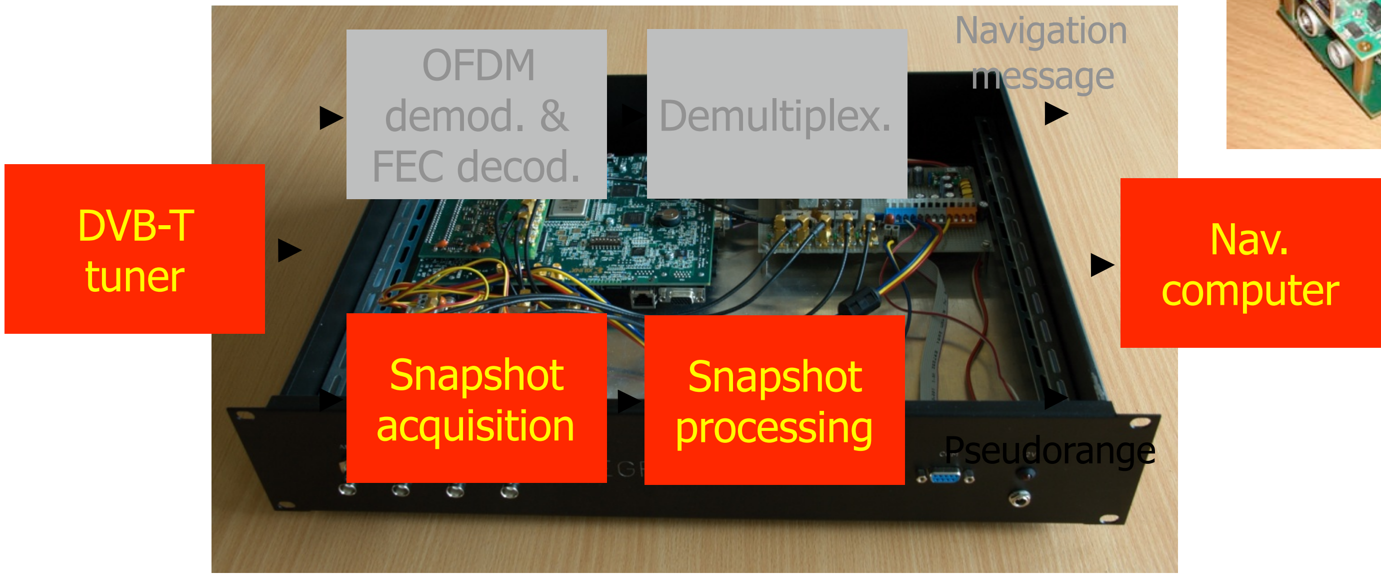
DVB-T
signal gen.

DVB-T Navigation Receiver Revision

Low performance

Higher performance hardware



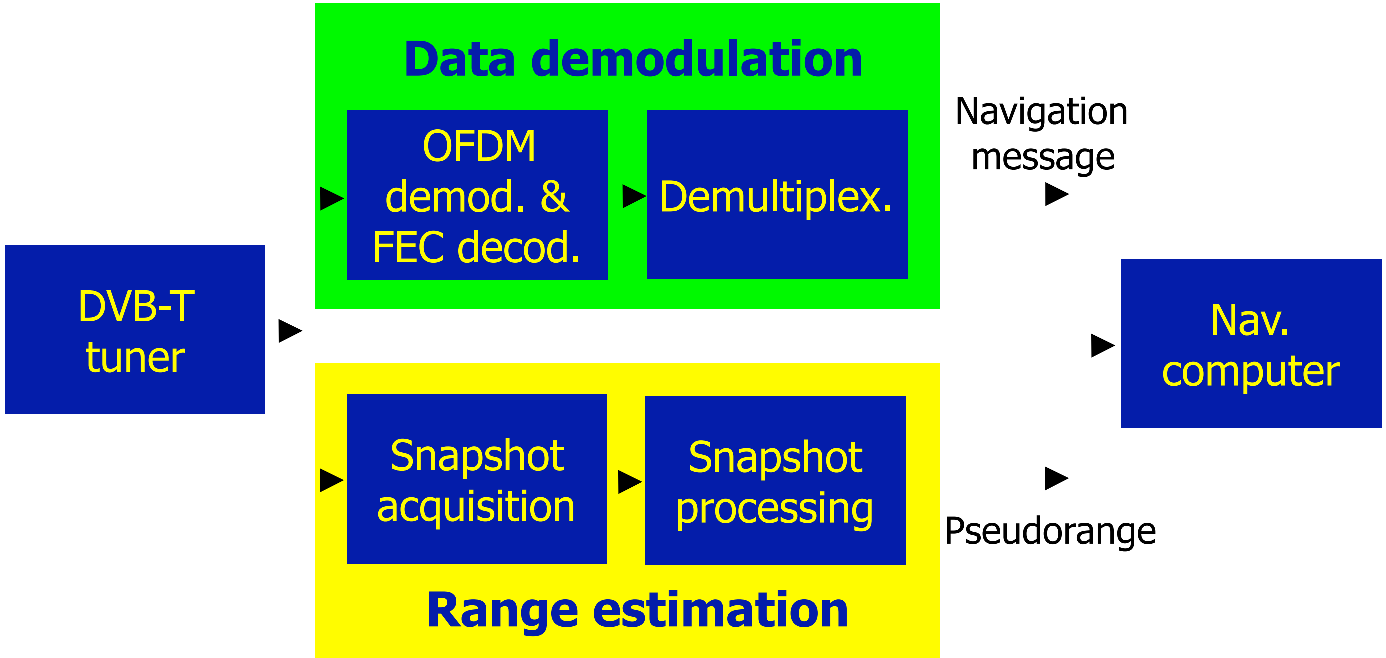
- Snapshot duration 2 ms
- Acquisition period 100 ms

=> Continual measurement

- Frequency tuning 500 ms

<20 ms – fractional space synthesizer

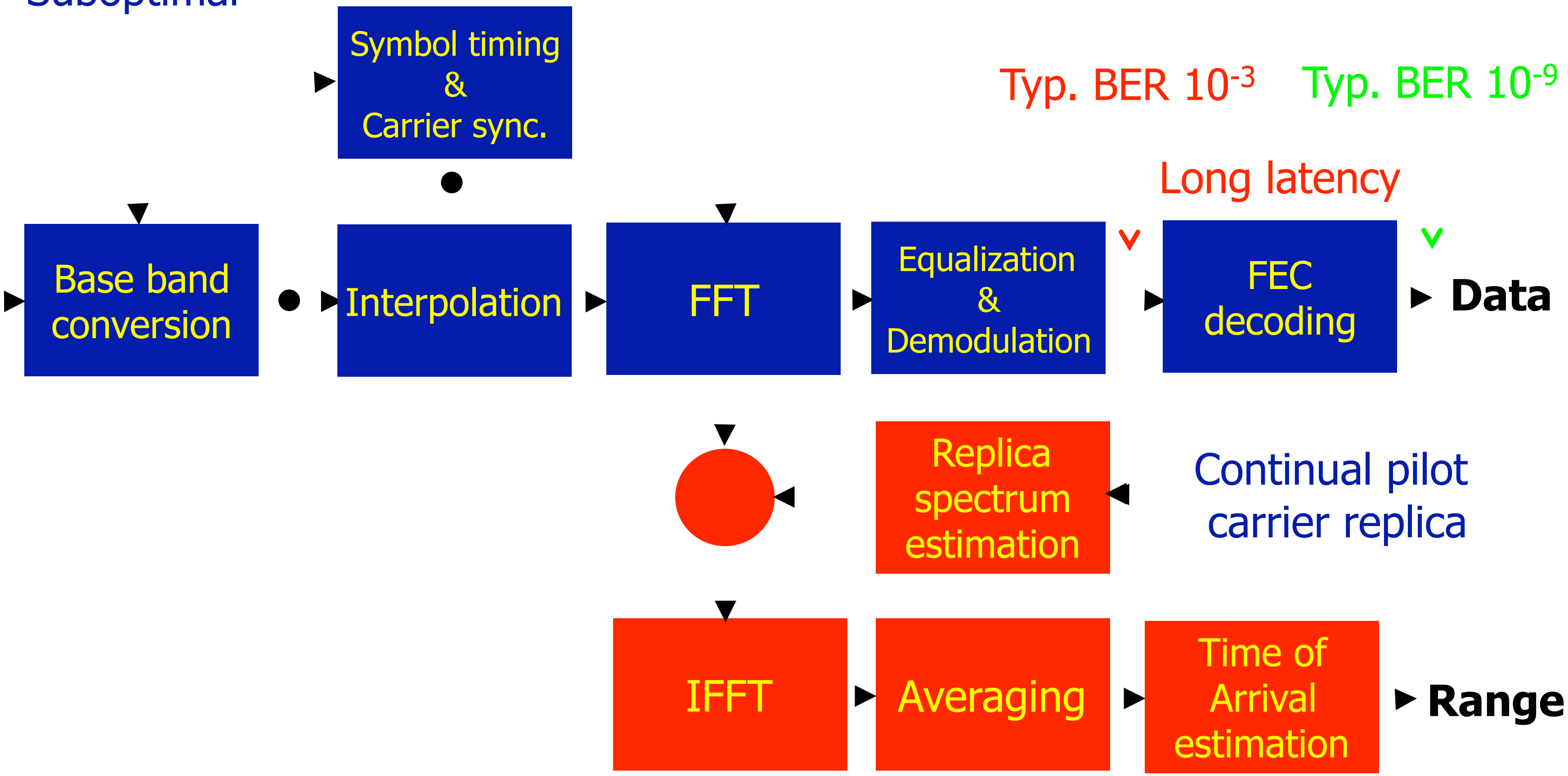
Independent Data Demodulation and Ranging



Integrated OFDM Demodulation and Range Measurement

OFDM Snapshot navigation

- Whole replica energy for range measurement
- Simple signal generation
- Suboptimal



Conclusions

- Modern mobile navigation systems will not use GNSS signals only but also different terrestrial signals
- Candidate systems mostly utilize OFDM modulation
- OFDM modulated signal can be used for high precision ranging
- OFDM demodulator and tracking can be tightly integrated

Thank you for your attention

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