Increasing receiver dynamic range for Low Power Wide Area Networks

Gerald Ulbricht, Jakob Kneißl, Josef Bernhard, Gerd Kilian

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Low Power Wide Area Networks (LPWA Networks)
Motivation

Selected early LPWA market applications and their key requirements

See http://www.analysysmason.com/Research/Content/Reports/LPWA-advantages-disadvantages-May2015-RDME0/#19%20May%202015

Low Power Wide Area Networks (LPWA Networks)
Motivation

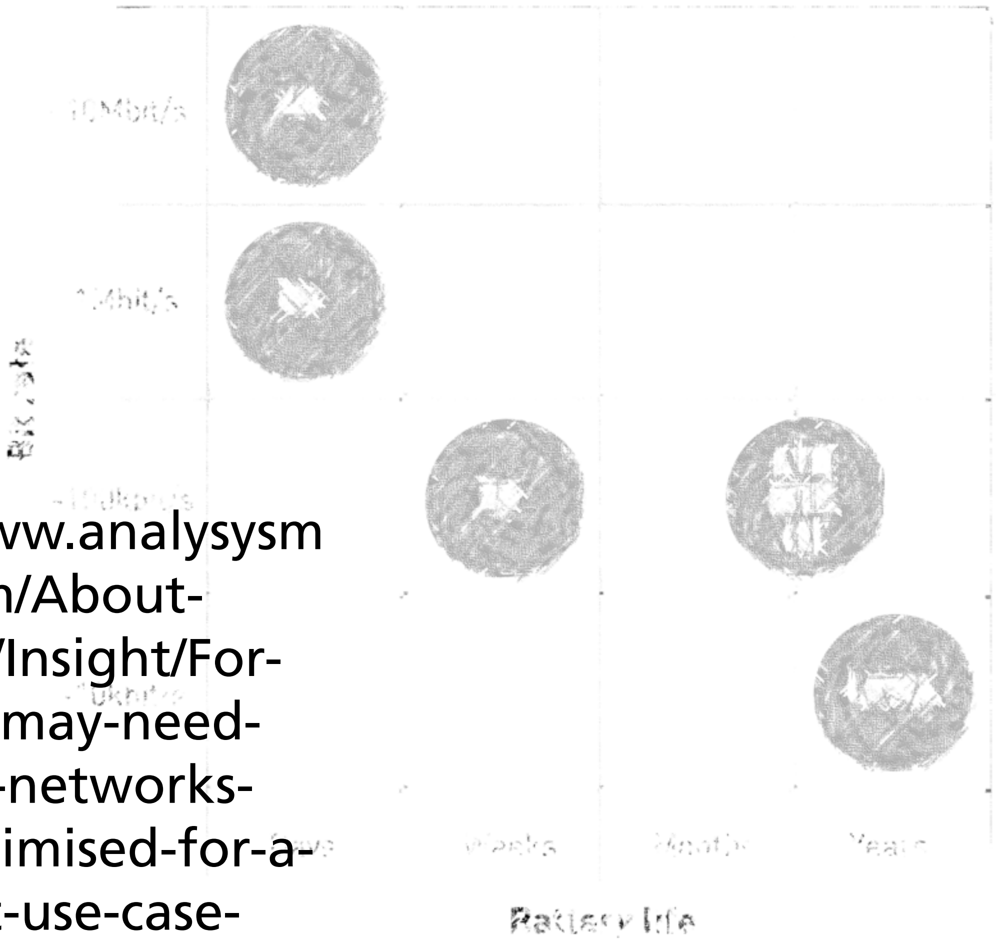
IOT applications have a demand for alternative solutions to cellular M2M

LPWA networks are optimal if

- low cost of operation
- long battery operation
- high coverage area

is required

See http://www.analysysmason.com/About-Us/News/Insight/For-IoT-CSPs-may-need-multiple-networks-each-optimised-for-a-different-use-case-/#29%20April%202015

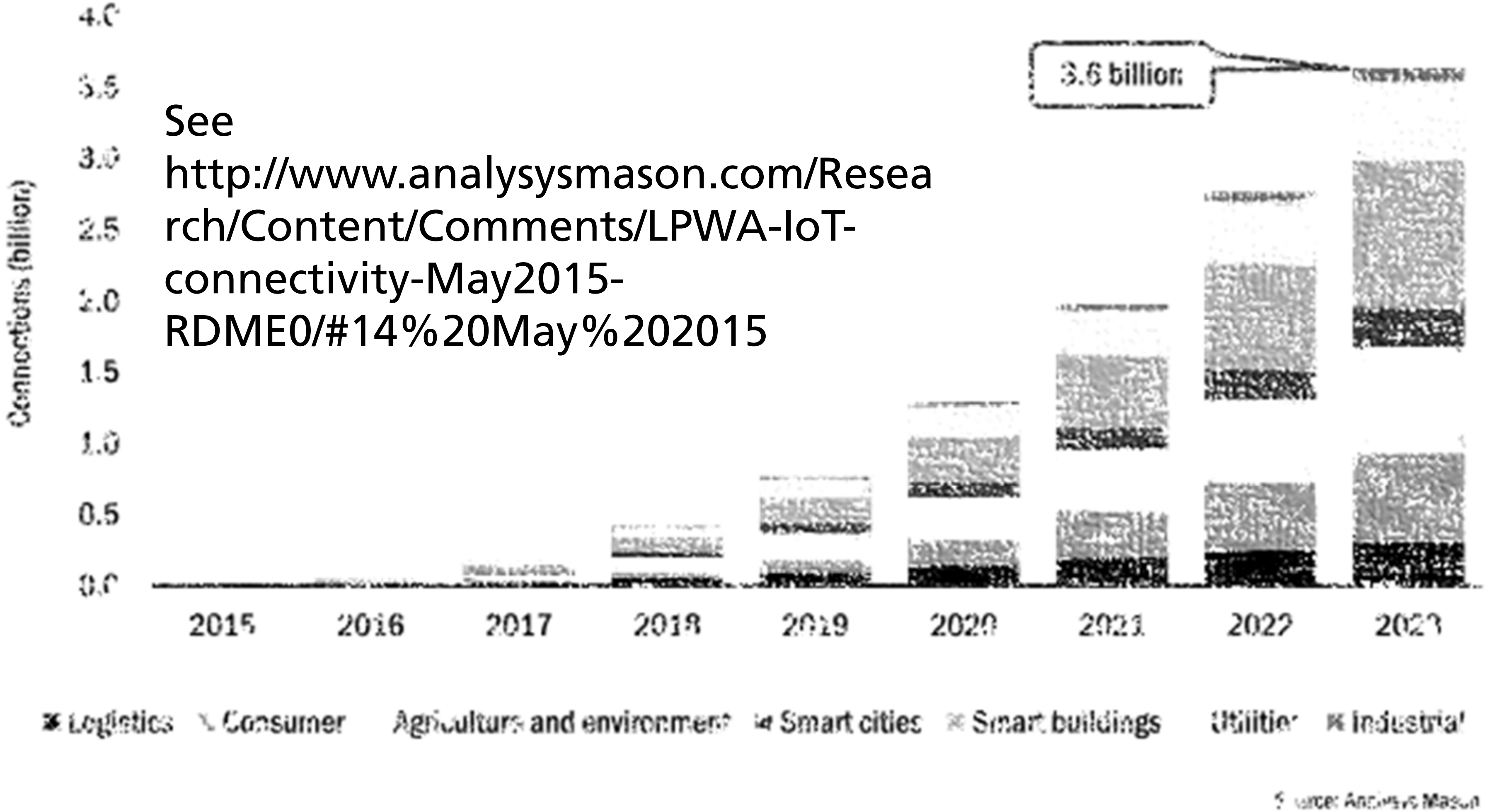


[Source: Analysys Mason, 2014]

Low Power Wide Area Networks (LPWA Networks)

Motivation

LPWA connections forecast, worldwide, 2015 - 2023



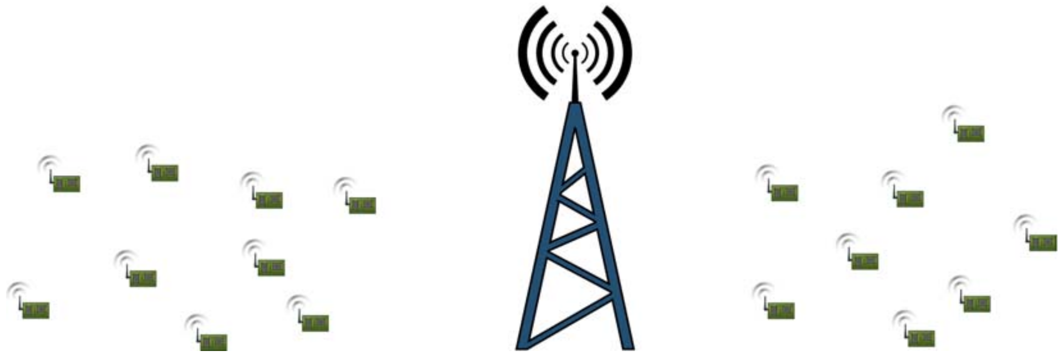
See http://www.analysysmason.com/Research/Content/Comments/LPWA-IoT-connectivity-May2015-RDME0/#14%20May%202015

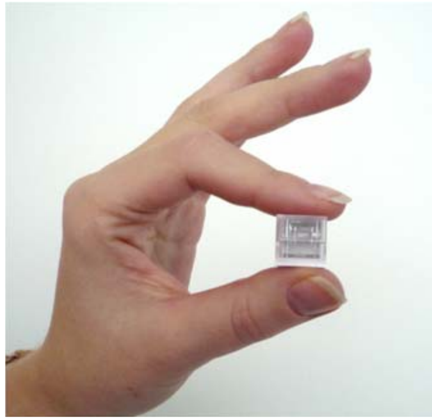
Overview

1. Motivation for LPWA networks
2. MIOTY Telegram Splitting technology – a new LPWA network approach
3. Motivation for high dynamic range in the receiver
4. Parallel ADC technology
5. Simulation results
6. Conclusion

LPWA Networks
Characteristics

Low Power Wide Area Networks as a cost optimized solution





- Central high performance receiver
- Small low complex and low cost „object devices“
- Network capacity of several thousand „objects“
- Small amount of transmitted data at irregular times a day
- Mostly operated in unlicensed Sub-GHz bands
- Low data rate

MIOTY Telegram-Splitting Technology
Technical facts

MIOTY

Low Power Wide Area network

- Based on an asymmetric transmission method, simple and low-cost sensor nodes and a complex receiver connected within a star topology
- The MIOTY Telegram-Splitting protocol can be easily implemented on commercial radio frequency chips
- Resistant against other radio systems
- System can be customized for different applications
- Permanent master installation in the metropole area of Nuremberg, Germany
- Adjustable frequency band between 133 to 966 MHz
- Especially designed for minimal data transmission with low bit rates

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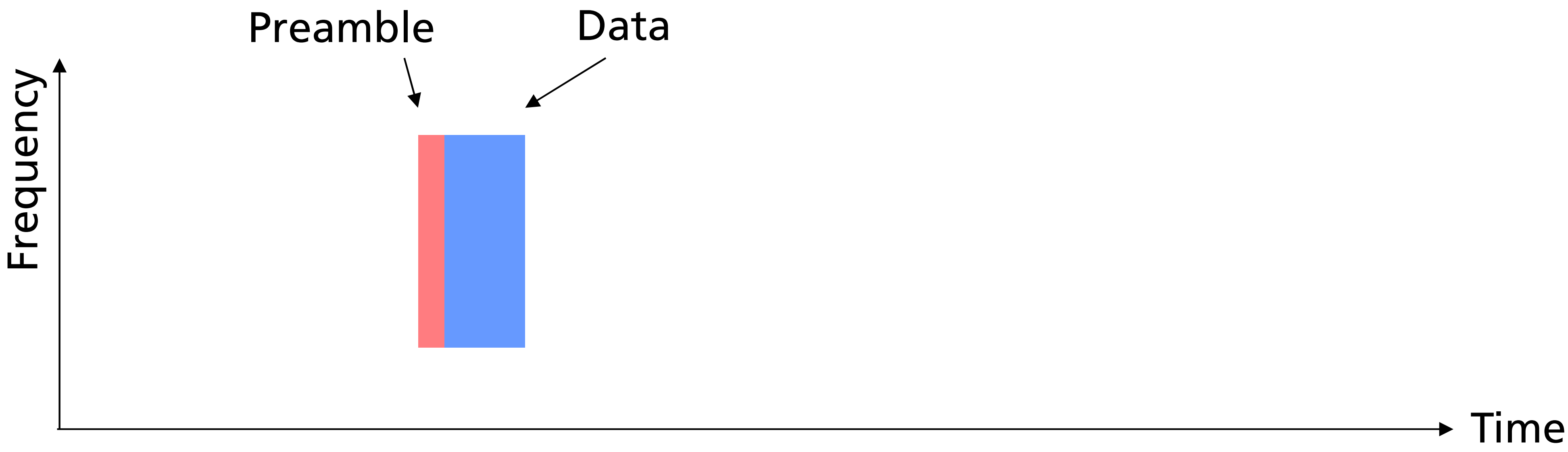
MIOTY Telegram-Splitting Technology
Key advantage over existing technologies



- Current sub-GHz systems: 4 – 50 ms packet length @ high BW

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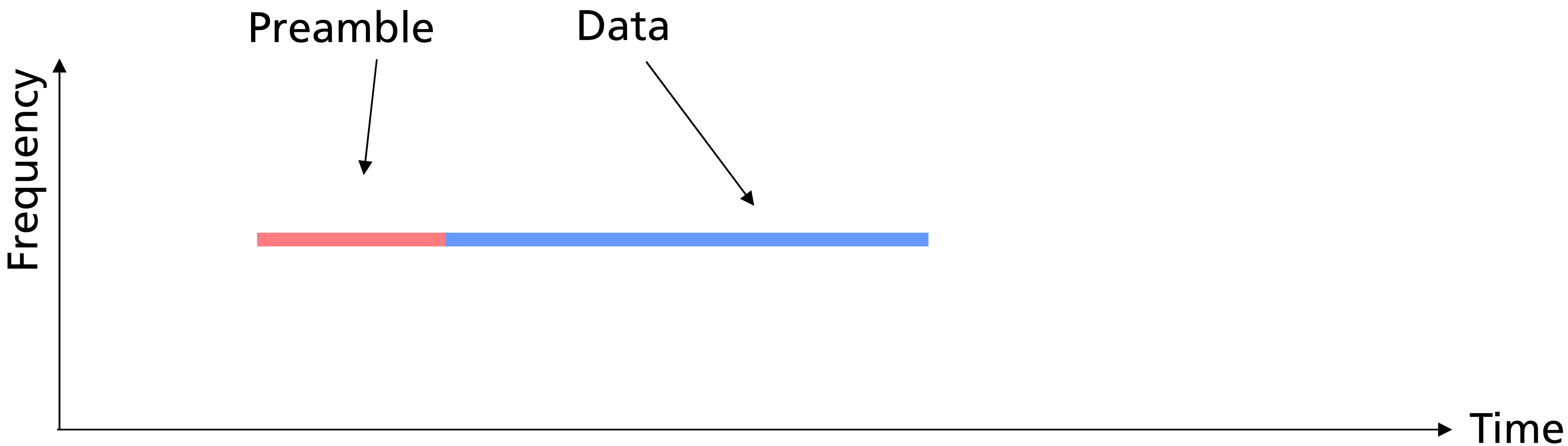
MIOTY Telegram-Splitting Technology
Key advantage over existing technologies



- Current sub-GHz systems: 4 – 50 ms packet length @ high BW
- Current LPWA solutions: 0.5 – 2 s packet length @ low BW

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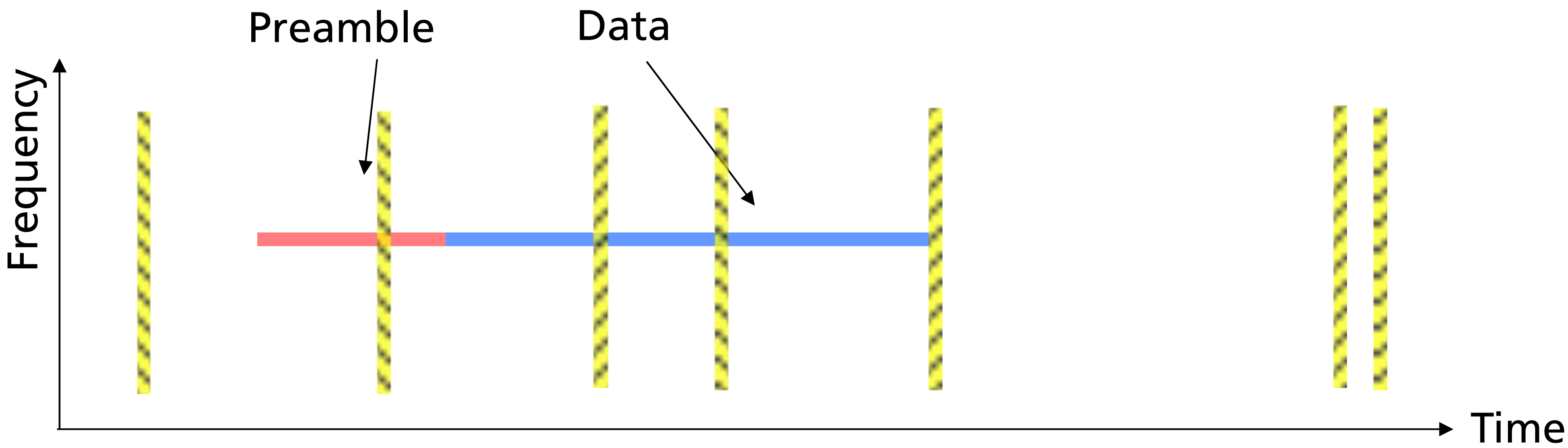
MIOTY Telegram-Splitting Technology

Key advantage over existing technologies



- Current sub-GHz systems: 4 – 50 ms packet length @ high BW
- Current LPWA solutions: 0.5 – 2 s packet length @ low BW
- Challenge: Many short interferer

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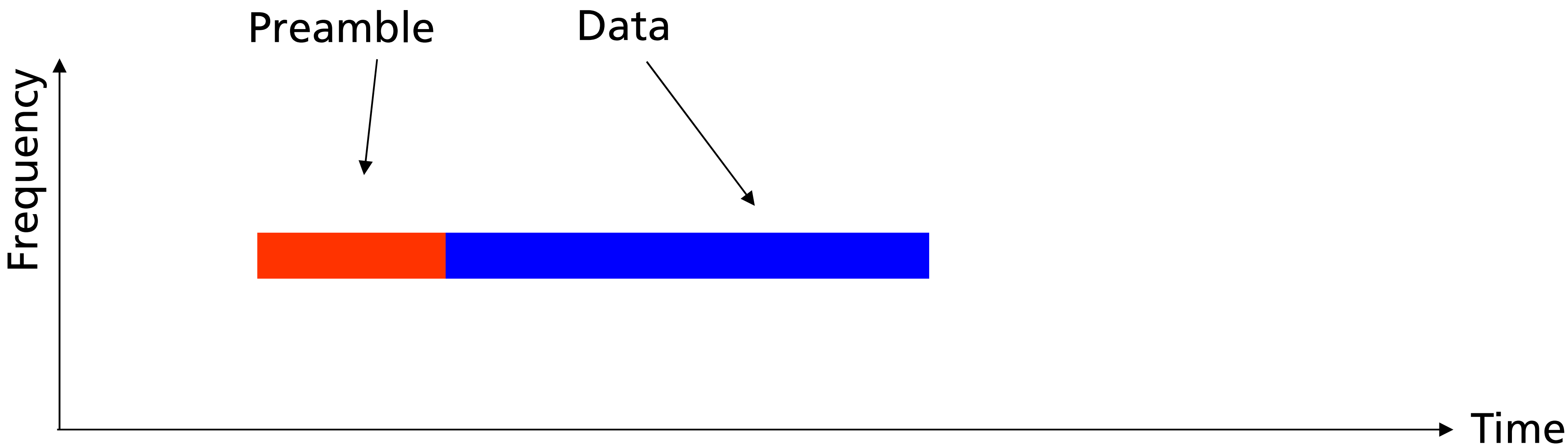
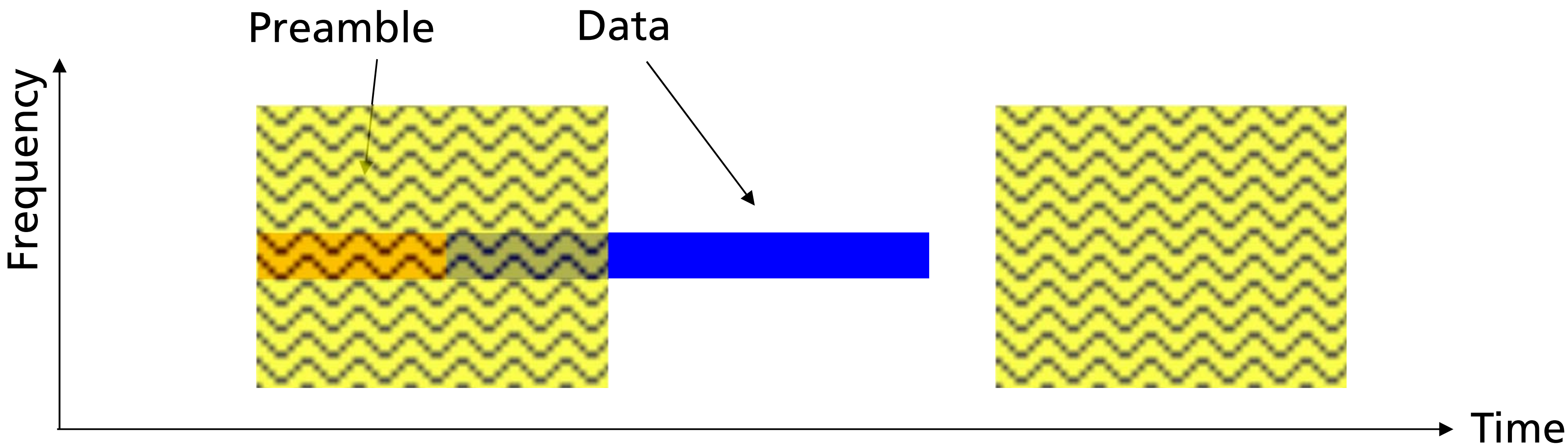
MIOTY Telegram-Splitting Technology
Key advantage over existing technologies



- Current sub-GHz systems: 4 – 50 ms packet length @ high BW
- Current LPWA solutions: 0.5 – 2 s packet length @ low BW
- Fraunhofer Telegram-Splitting Technology
  - Additional error correction to improve robustness

MIOTY Telegram-Splitting Technology
Key advantage over existing technologies



- Current sub-GHz systems: 4 – 50 ms packet length @ high BW
- Current LPWA solutions: 0.5 – 2 s packet length @ low BW
- MIOTY Telegram-Splitting Technology
  - Additional error correction to improve robustness
  - But still long interferer are a challenge

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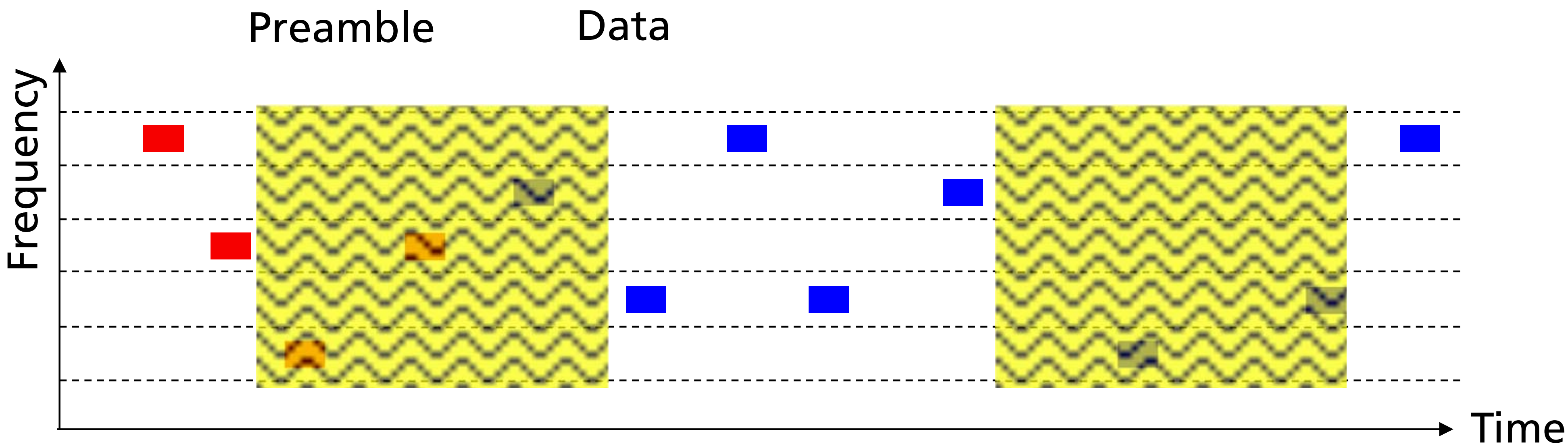
MIOTY Telegram-Splitting Technology

Key advantage over existing technologies



- MIOTY Telegram-Splitting technology
  - Telegram-Splitting (USP): Spreading packet over time and frequency
  - Additional error correction to improve robustness
  - Extremely robust against loss of several hops (up to 50%)
  - Works with most common sub-GHz chipsets
  - Optimized for battery operation

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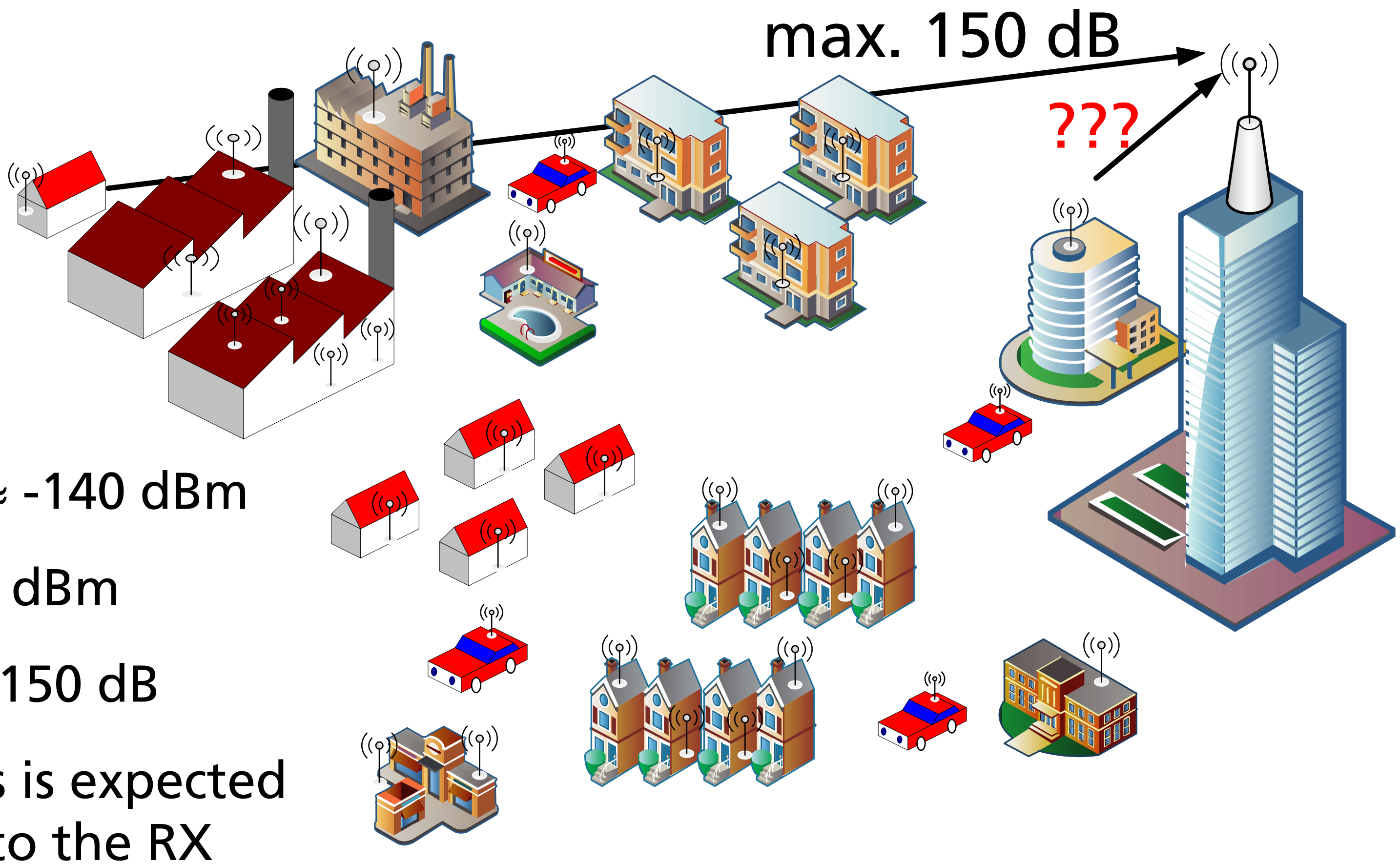
MIOTY Telegram-Splitting Technology

Challenge: Receiver dynamic range



Near far problem

- RX sensitivity ≈ -140 dBm
- TX power = 10 dBm
- Link budget ≈ 150 dB
- What path loss is expected for a TX close to the RX

➢ This defines the required dynamic range of the RX

➢ Cannot be solved by Automatic Gain Control

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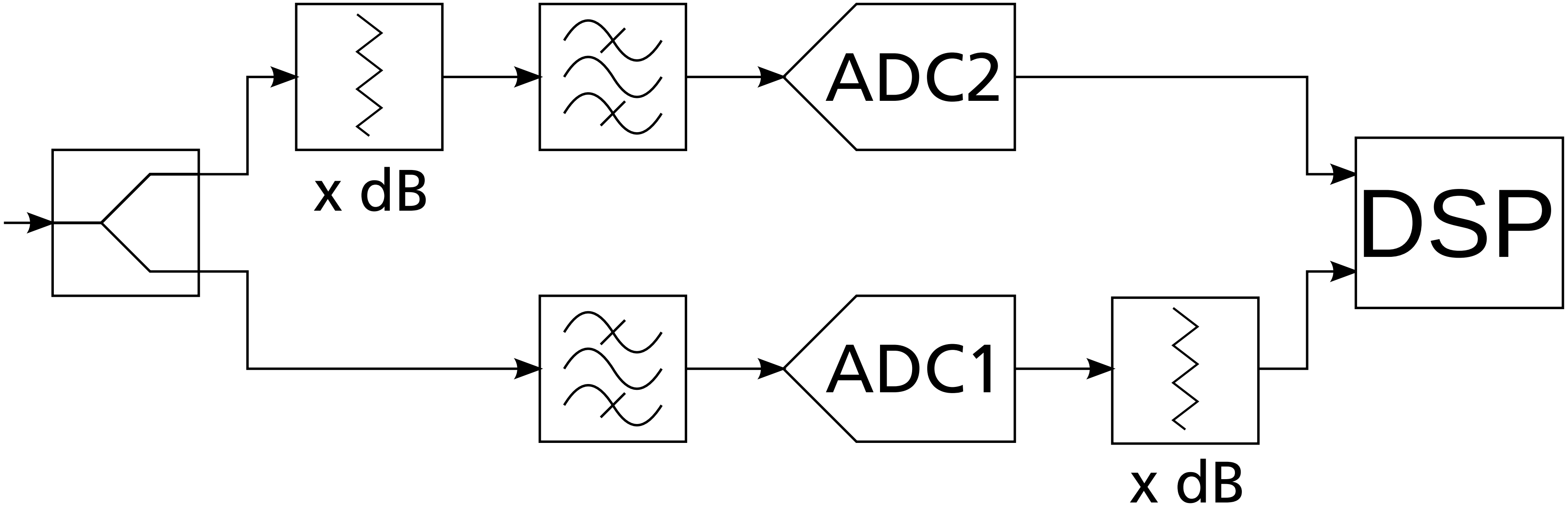
Improved Receiver Dynamic by ADC Diversity
Architecture



- Two parallel ADCs sampling simultaneously the input signal with the same clock
- Attenuator causing a different drive level at the ADCs, compensated in the digital domain
- DSP combines signals from the two branches

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Improved Receiver Dynamic by ADC Diversity
Signal processing

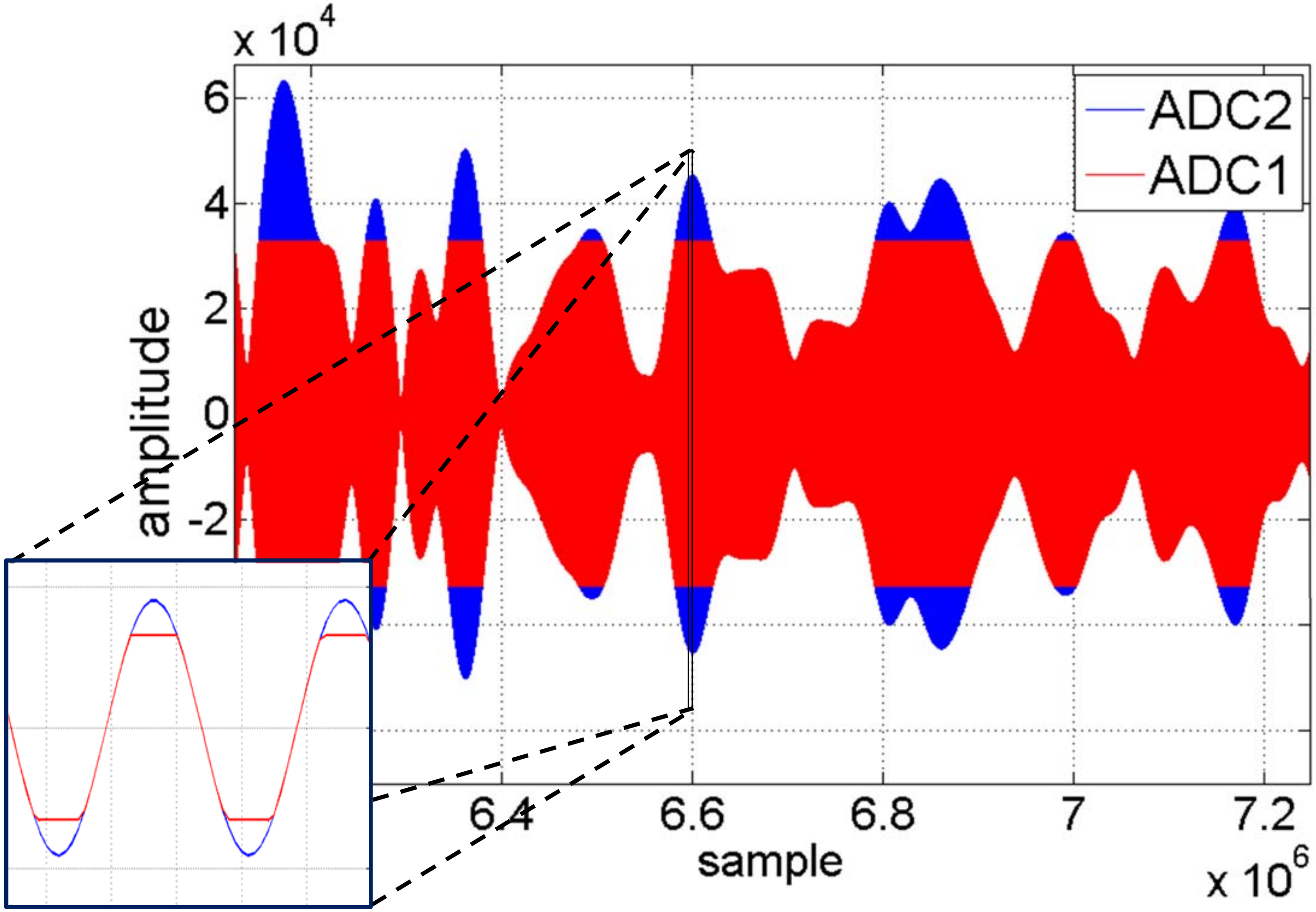
- Signal averaging (see [2]):
  - Same drive level at the ADCs (x = 0 dB)
  - If noise is uncorrelated, SNR improves by 3 dB
- Stacked ADCs (see [3]):
  - Different drive level at the ADCs
  - If sample of ADC1 is clipped, the sample of ADC2 is chosen
  - SNR improvement up to 8 dB possible depending on the waveform
- Combination of both (see [4]):
  - Different drive level at the ADCs
  - If sample of ADC1 is clipped, the sample of ADC2 is chosen
  - Gain Weighted Combining (GWC) if ADC1 is not clipped

Model of a Stacked ADC configuration
Sampling a 64-QAM signal

≈10% of the samples saturate ADC1

⇓

90% of the time ADC1 is working with lower noise level



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Model of a Stacked ADC configuration
Sampling a sinusoidal signal

6 dB attenuation

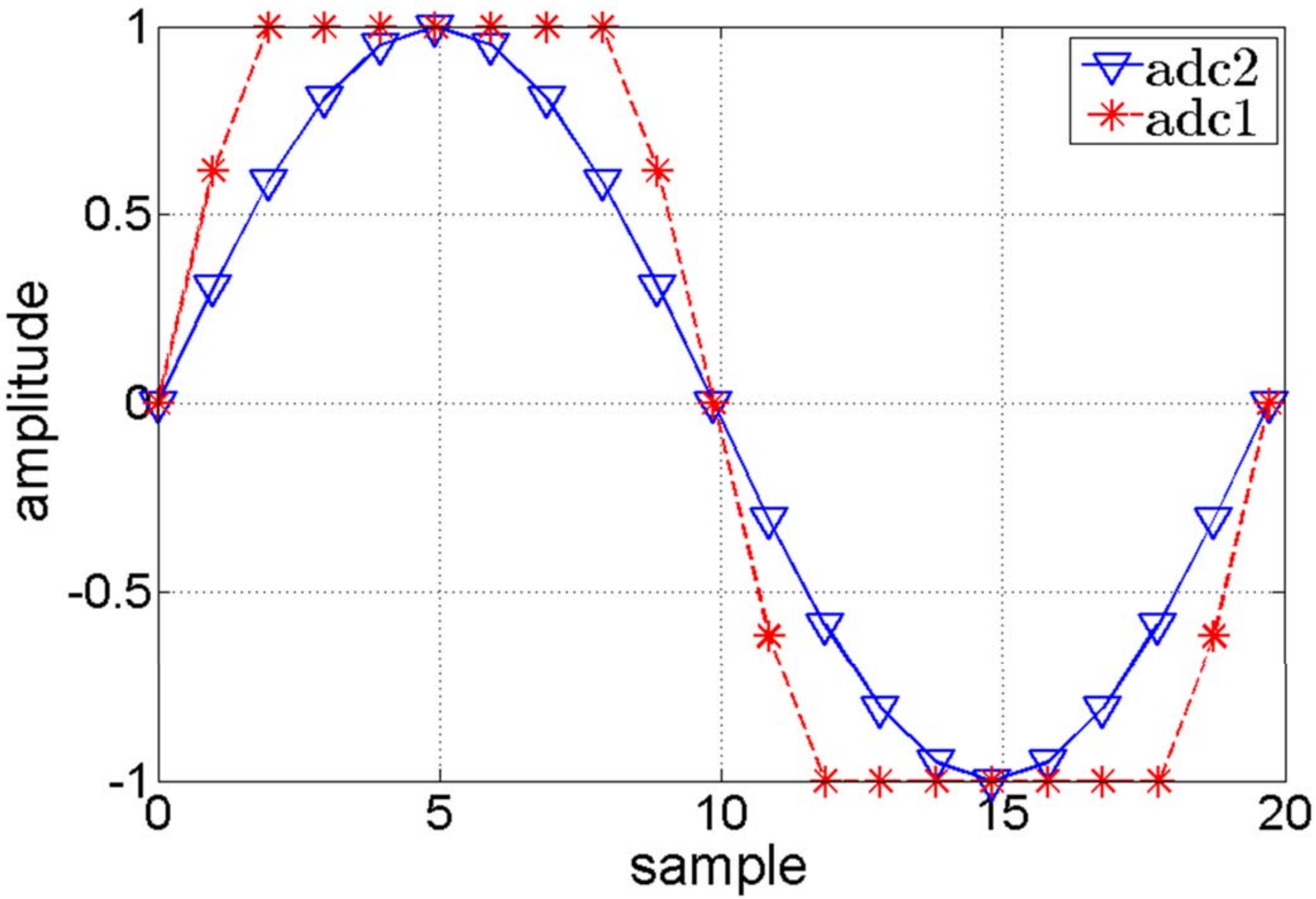
⇓

twice the amplitude at ADC1

≈30% of the samples saturate ADC1

⇓

70% of the time ADC2 is working with higher noise level



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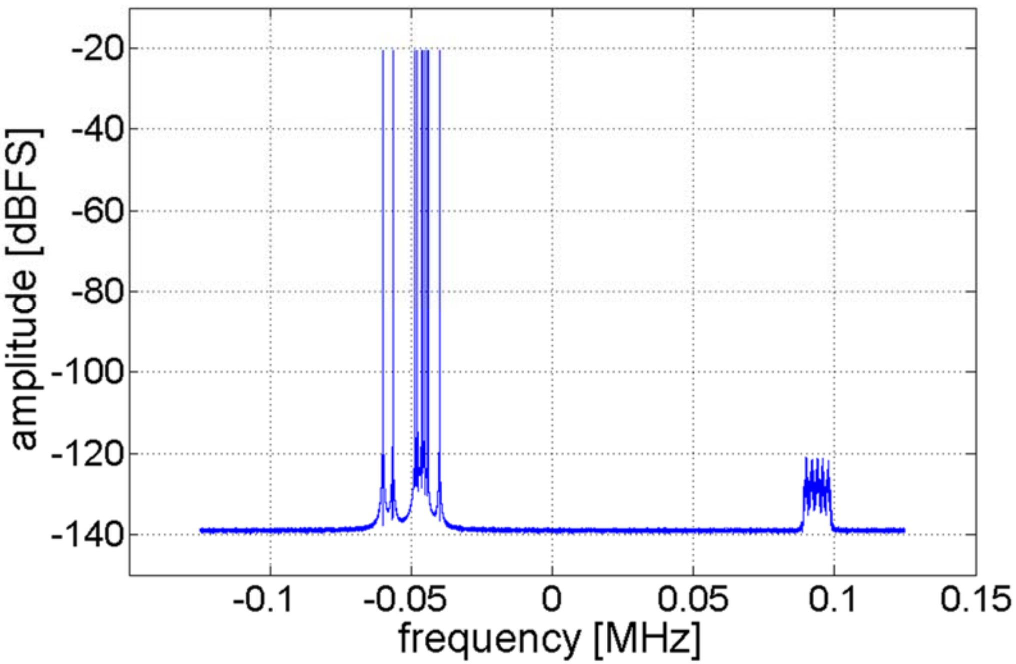
Improved Receiver Dynamic by ADC Diversity
Simulation setup

Input signal:

- Strong interferer: 10 unmodulated carriers
  - Amplitude: maximum peak 1 dB below full scale level of ADC2 (Attenuator = 6 dB ⇒ ADC1 saturated by 5 dB at peak level)
  - Center frequency: -50 kHz (complex baseband)
- 100 telegrams of the MIOTY Telegram-Splitting signal
  - Amplitude: 100 … 111 dB below one of the interfering carriers
  - Center frequency: 90 kHz (complex baseband)
- sampled with 250 kHz



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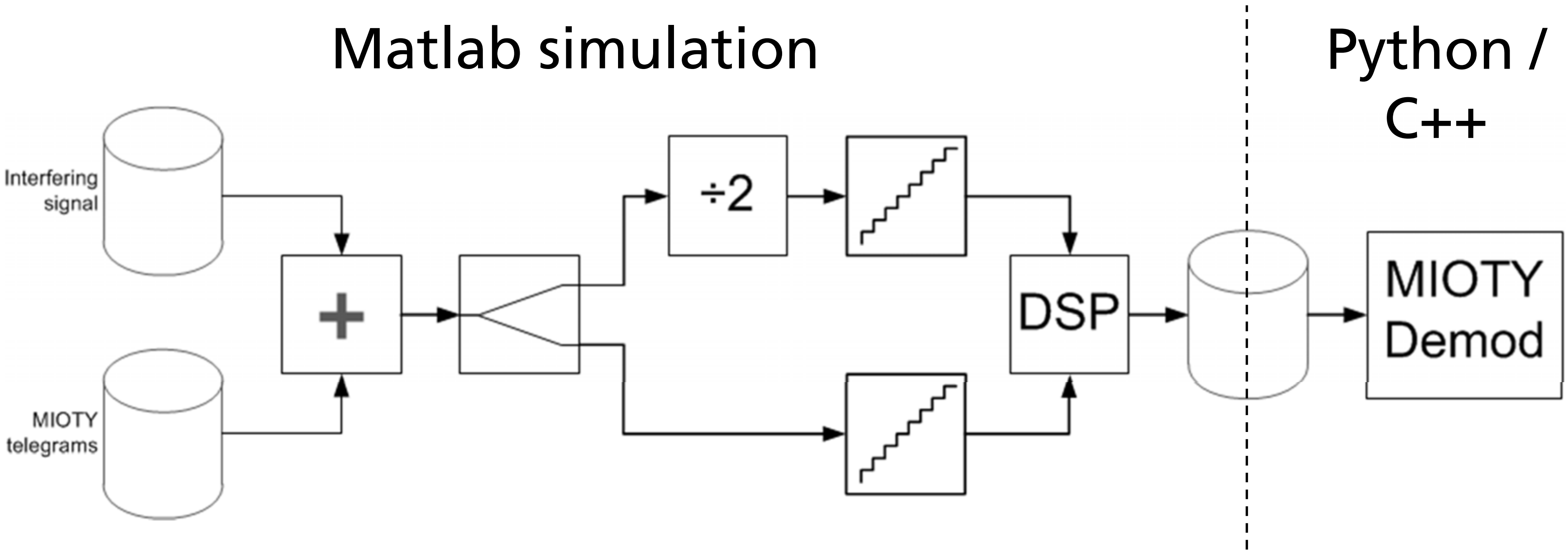
Improved Receiver Dynamic by ADC Diversity
Simulation setup

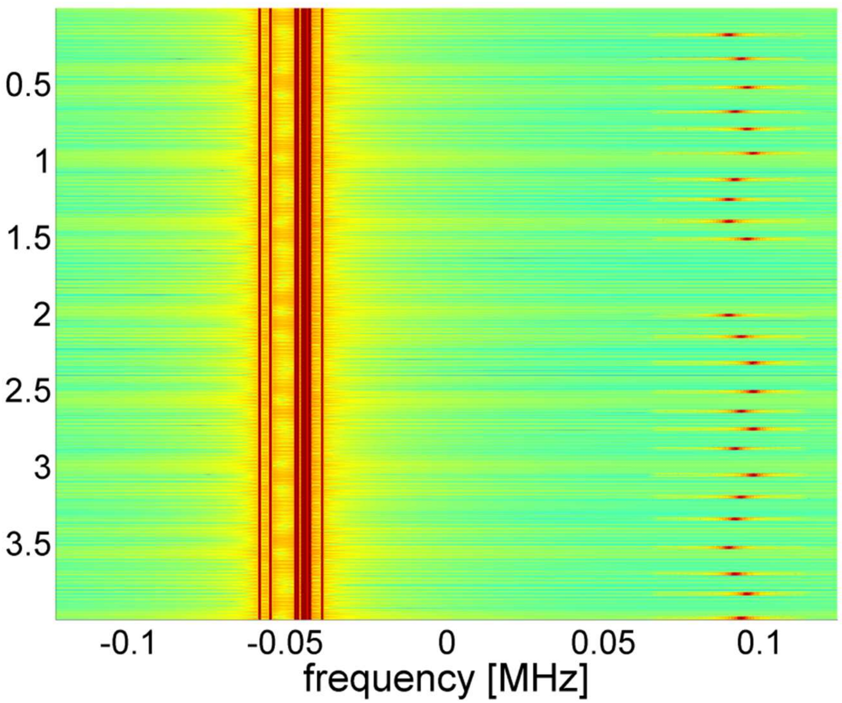


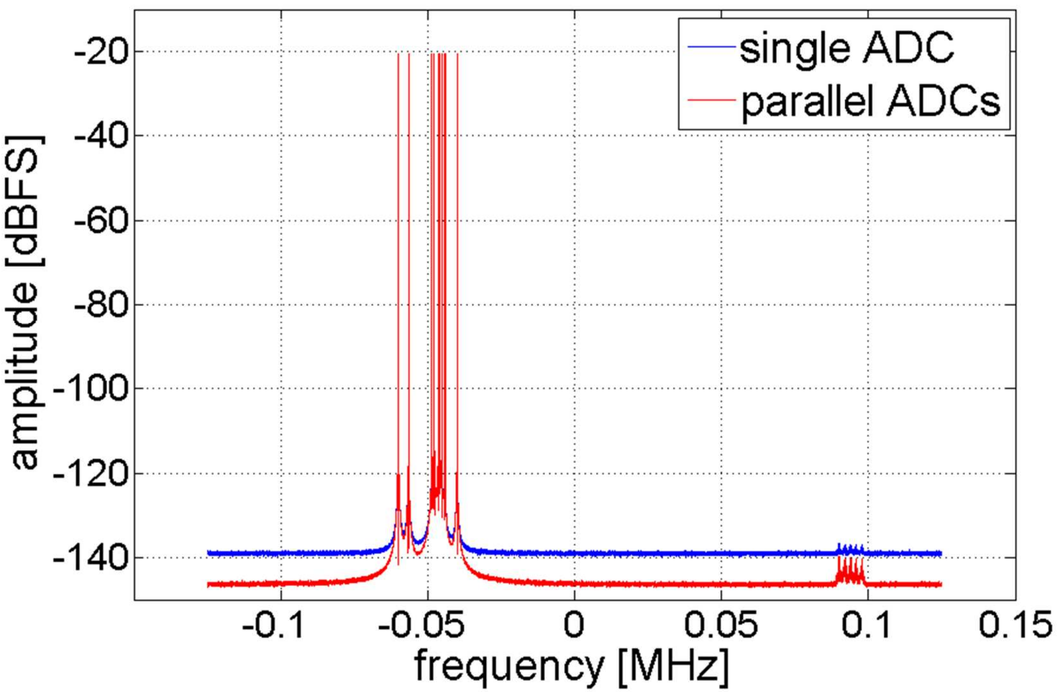
Digital Signal Processing:

Ideal quantization and combination (Stacked + GWC) with Matlab

Demodulation of the Telegram-Splitting signal with MIOTY RX (Python, C++)

Improved Receiver Dynamic by ADC Diversity
Simulation results





- Signal-to-noise ratio within the channel of the MIOTY channel improves by 7.4 dB in compared with a single ADC

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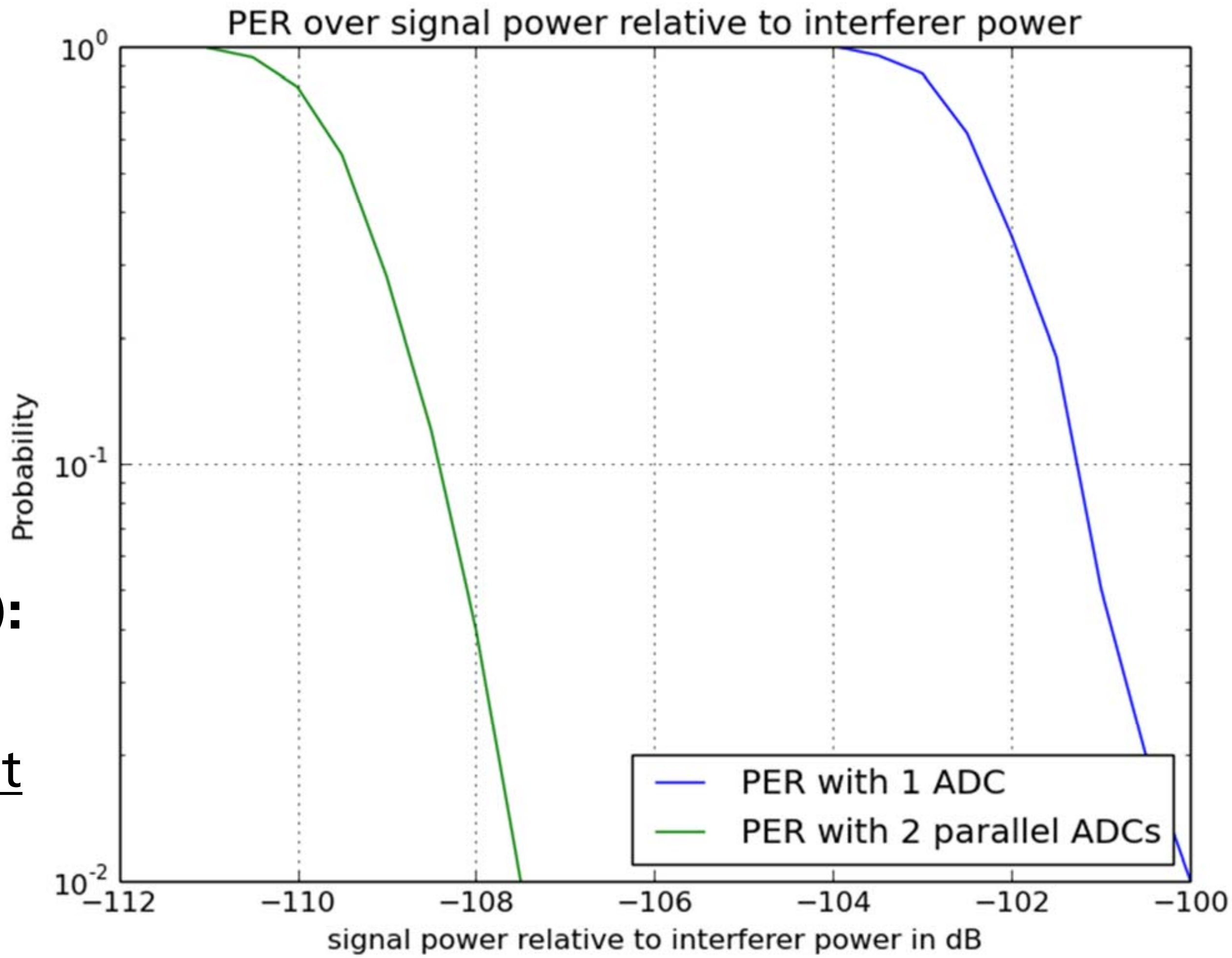
Improved Receiver Dynamic by ADC Diversity
Simulation results

- Interferer level kept constant
- MIOTY signal varied between -111 … -100 dB below interferer
- Quantization by 1 or 2 parallel ADCs

Improvement of the Packet Error Rate (PER):

➢ with parallel ADCs the same PER is achieved at 7 dB lower signal power than with a single ADC



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Increasing receiver dynamic range for LPWA Networks
Summary

- MIOTY Telegram-Splitting is a waveform designed for robust, narrowband radio communication over long ranges
- MIOTY transmits data of several thousands of transmitters over long distances (up to 15 km) but with an extremely low power consumption (battery life ≈ 15 years)
- Near-far problem demand for high instantaneous RX dynamic range
- Parallel ADC technology has the potential to increase RX dynamic range where AGC is no option
- Simulations show that ADC diversity can improve the dynamic range of the RX by more than 7 dB (depending on the interference scenario)
- Next steps:
  Measurements with a low cost Software Defined Radio (e.g. USRP)

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Increasing receiver dynamic range for LPWA Networks
References

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[2] Seifert, E.; Nauda, A., “Enhancing the dynamic range of analog-to-digital converters by reducing excess noise,” *IEEE Pacific Rim Conference on Communications, Computers and Signal Processing*, pp. 574–576, 1989

[3] Ulbricht, G., “Experimental Investigations on a Stacked Analog-to-Digital Converter Configuration for a High Dynamic Range HF Receiver,” *German Microwave Conference*, 16. – 18. March 2015 in Nuremberg

[4] Chen, Ying; Pollok, André; Haley, David; Davis, Linda M., „ADC Diversity for Software Defined Radios,” Proceedings of the SDR-WInnComm 2013, pp.181-186, 8. – 11. January 2013 in Washington, DC

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Thank you for your attention!
Questions?

Snapshot: Webcam at our DVB-SH-Antenna in Erlangen

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