# Wireless Intra-spacecraft Communication

## Evaluation of Bluetooth Low Energy Wireless Internal Data Communication for Nanosatellites

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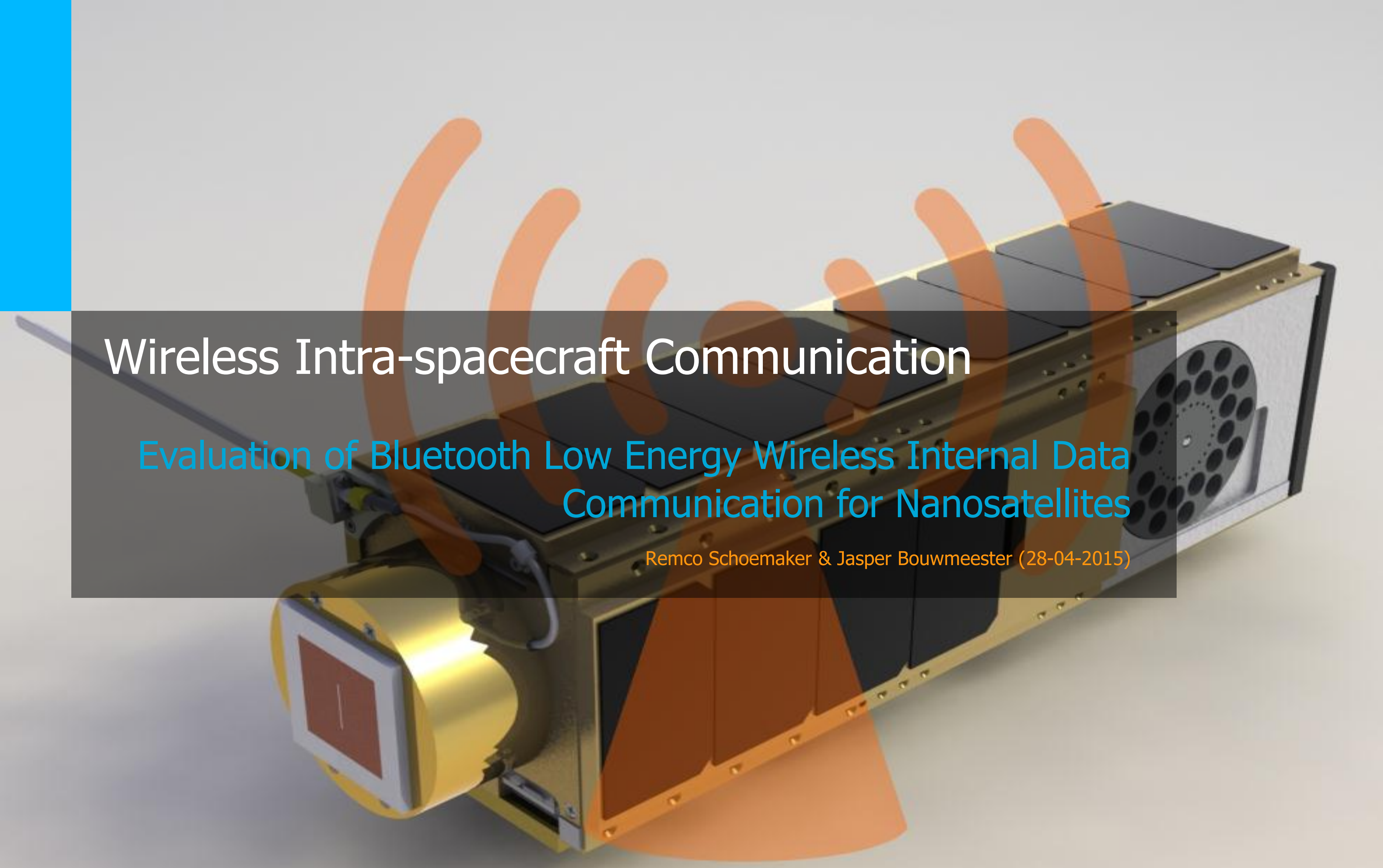


Courtesy of NASA Ames Research Center

# Introduction

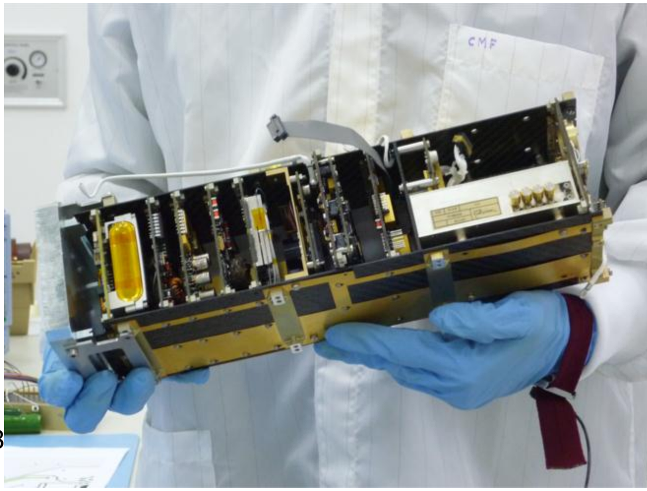
- Why wireless intra-spacecraft communication?
  - Reduce wiring integration complexity
  - $I^2C$ interface Delfi-n3Xt and Delfi-C3 experienced reliability issues
- Potential problems
  - Electromagnetic Interference (EMI)
  - Power consumption
  - On-ground wireless communication experiments in a CubeSat have been conducted

# Presentation outline

- Past wireless intra-spacecraft communication experiments
- Hardware & wireless protocol selection
- Discussion about results of experiments
- Wired versus wireless nodes
- Proposal wireless experiment on-board DelFFi
- Conclusions

# Past wireless intra-spacecraft communication experiments

- Delfi-C3 Autonomous Wireless Sun Sensor (AWSS)
  - Quadrant detector powered by solar cell
  - nRF9E5 System on a Chip (SoC)
  - 1 GHz RF SoC
- Optical Wireless Links to Intra-Spacecraft (OWSL) communication experiments
  - Nanosat-01
    - Bit Error Rate (BER) for 200 kbps did not exceed $10^{-8}$
    - BER higher at South Atlantic Anomaly
  - OPTOS
    - Wireless Controller Area Network (CAN) bus
    - 950 nm at 125 kbps



Courtesy of CALSENS/INTA

# Past wireless intra-spacecraft communication experiments

- Norwegian University of Technology Test Satellite (NUTS)
  - Wireless bus: nRF24L01 ultra low power transceivers
  - Maximum raw data rate: 2 Mbps
- TU Delft research
  - ZigBee PRO protocol and ZigBit hardware
  - Data arrival delays: ~30 ms
  - Devices stayed awake for 120 ms which leads to higher power consumption

# Wireless protocol selection

- Extensive wireless protocol trade-off
  - ZigBee
  - ANT
  - Infrared Data Association (IrDA)
  - Low Power Wi-Fi
  - Bluetooth Low Energy (BLE)

- Bluetooth Low Energy was selected
  - Favorable power consumption and achievable data rates
  - IrDA: Line-of-sight problems
  - Wi-Fi overkill for most applications, maybe for high data rate payload
  - ZigBee slightly worse than BLE

# Hardware selection

- BLE113 module of Bluegiga Technologies
  - Very power efficient and small
  - Transmitting mode (TX): 18.2 mA at 3.3 V
  - Receiving mode (RX): 14.3 mA
  - Sleep modes: 0.5 to 270 µA
- Achievable data rates
  - Theoretical effective throughput: 270 kbps
  - Best throughput observed: 100 kbps

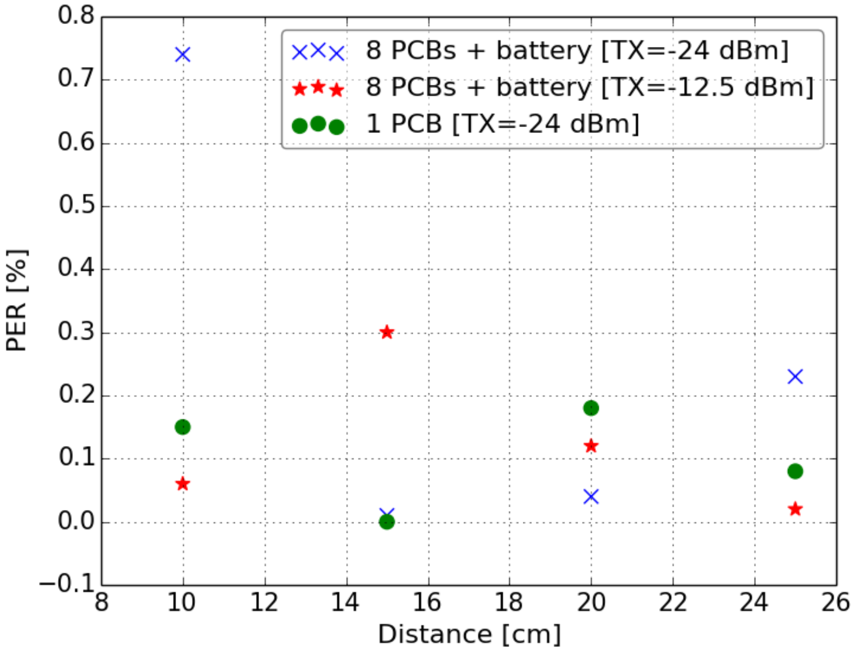
Courtesy of Bluegiga technologies

# Experimental setup

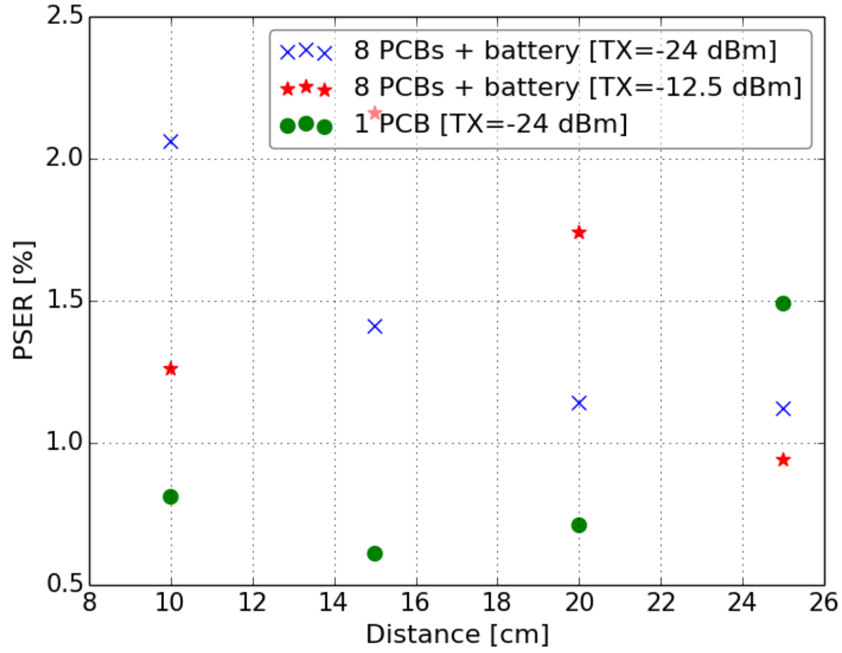
- Determine performance of BLE113 modules in CubeSat environment
- Representative nanosatellite model
  - Vary distance, PCBs, power profile etc.
  - Power consumption measured
  - Packet Error Rates (PERs) determined
- Delfi-C3 spare model
  - Check for electromagnetic interference

# Results: Influence of module distance

**Distance vs Packet Error Rate**

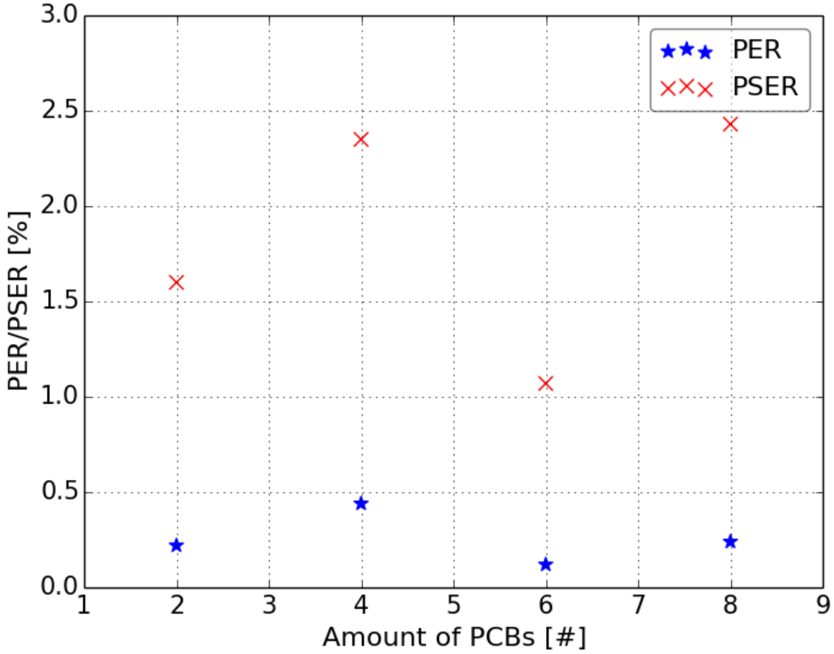



**Distance vs Packet Sent Error Rate**

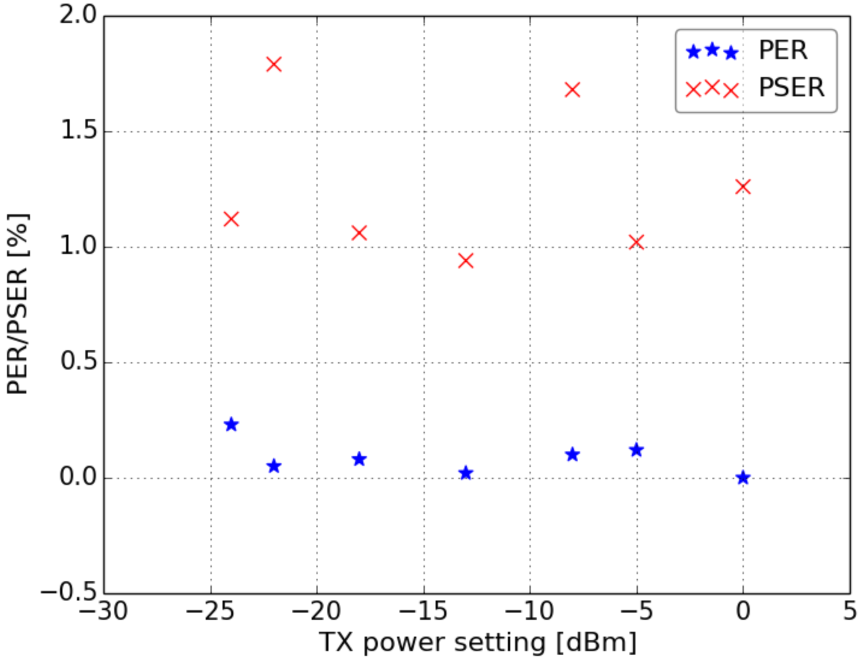


# Results: Amount of printed circuit boards & TX power setting

**PCBs vs Packet (Sent) Error Rate**

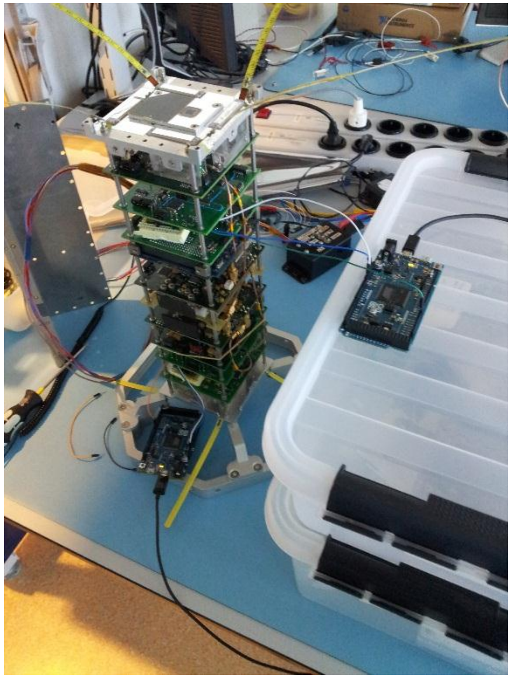



**TX power vs Packet (Sent) Error Rate**



# Results: Delfi-C3 spare model

- Packet (Sent) Error Rate clearly higher if satellite was powered on
  - Total Packet Error Rates only few percent higher
  - Harmonics of transceiver?
- S-band systems
  - BLE uses Adaptive Frequency Hopping

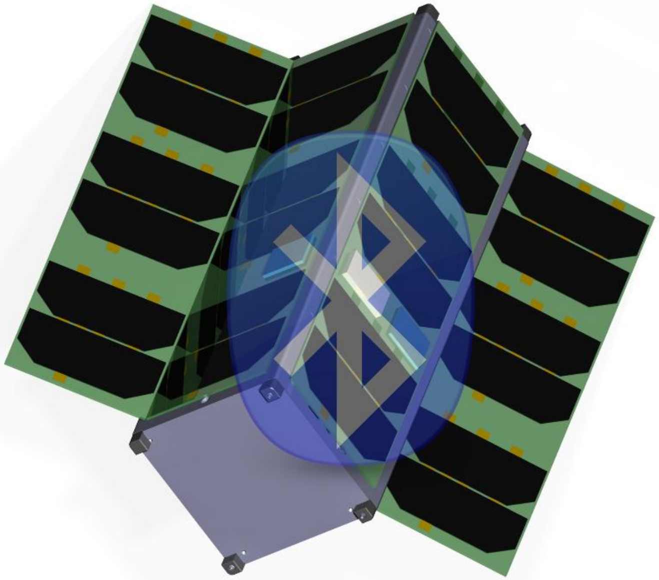


# Wired versus wireless nodes

- Connection stability is excellent
- Power consumption
  - 1 Hz sun sensor: 2 mW – 30 $mm^2$ solar cell
  - 0.1 Hz wireless temperature sensor: powered by CR2032 coin cell, lifetime of six months
- Data integrity
  - BLE113: Implemented 24 bit Cyclic Redundancy Check
- Throughput wireless BLE
  - Acknowledged packets: 10 kbps
  - Non-acknowledged packets: 100 kbps

# Wireless BLE temperature sensor experiment on-board DelFFi

- Proof BLE technology in-orbit
- 0.1 Hz temperature sensor experiment
- Powered by a small solar cell
- Super capacitors allow operation during eclipse



# Conclusions

- BLE113 modules provide excellent connection stability and performance in a nanosatellite
- EMI does affect Packet Error Rates of BLE113
- Compatibility with S-band systems has to be checked
- In-orbit experiments on DelFFi or other nanosatellites will have to indicate radiation tolerance of BLE113 modules

# Image courtesy

- **Frontpage:** NASA Ames. A computer-generated image of the O/OREOS nanosatellite. URL: http://www.nasa.gov/images/content/469816main1_OOREOSRender2(PADOMClosed)_421.jpg.
- **OPTOS:** http://cal-sens.com/?p=2347&lang=en
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