

TUTORIAL PROPOSAL / IEEE IPIN 2026

FROM CHANNEL SOUNDING TO RING TRACKS

Hands-On Bluetooth Channel Sounding with nRF54 Development Kits

Dariusz Salami + Yusein Ali

Department of Information and Communications Engineering, Aalto University, Finland

Abstract

Reliable indoor positioning begins with understanding what a radio range measures and why it changes. This 180-minute tutorial introduces Bluetooth Channel Sounding through the SensWear physical AI platform and a controlled experiment between two Nordic nRF54 boards. A laptop running the `ble-channel-sounding` desktop application controls an nRF54LM20 development kit over native USB. The kit acts as the Channel Sounding Initiator and connects to an nRF54L15 development kit or two-antenna nRF54L15 Tag acting as the Reflector. Participants investigate how configuration, antenna orientation and obstructions affect the observations and the resulting distance estimates.

The first 105 minutes (1 hour 45 minutes) are a presentation connecting indoor-positioning concepts to the complete measurement procedure. Topics include the Bluetooth LE connection, initiator and reflector roles, phase-based ranging (PBR), round-trip time (RTT), frequency calibration, Modes 0–3, channel selection, and the organization of steps into subevents, events and procedures. We explain how the Ranging Service (RAS) delivers the reflector's observations, how security requirements affect configuration, and how controller timings, connection intervals and result traffic constrain the measurement budget. Inline PCT Transfer is introduced separately as a Core 6.3 option, subject to device support. Interactive predictions and an application walkthrough prepare participants for the lab.

After a 15-minute break, the instructors hand device kits to the groups for a 60-minute hands-on session. Participants explore the desktop tool, establish a known-distance baseline and make their own measurements. They compare RTT summaries with PBR phase-slope and inverse fast Fourier transform (IFFT) peak estimates, inspect controller reports and quality indicators, and investigate one change to orientation, obstruction or a supported configuration setting. Instructors guide the groups as they work. Each group saves its session, records the physical setup and discusses what changed in the observations or distance estimates.

Participants leave with a repeatable pairwise ranging workflow, saved configurations and recordings, and a method for testing a distance estimate against a reference. Wearable tracking provides the motivation: surveyed geometry, multiple ranges and a motion model are further stages beyond the core experiment. Preprogrammed boards remove the need for firmware development during the session. A built-in simulator supports the same software workflow without hardware; its synthetic output is explicitly distinguished from RF measurements.

Target and format

TARGET AUDIENCE

Graduate and advanced undergraduate students, researchers and practitioners in indoor positioning, wireless sensing, wearable computing, IoT and embedded systems. Basic radio or signal-processing knowledge is helpful; no prior Channel Sounding, Zephyr or firmware-development experience is required. Teams of three to four use the desktop application; Python programming is optional.

PROPOSED LENGTH

180 MIN

105 min presentation; 15 min break; 60 min group hands-on with supplied devices.

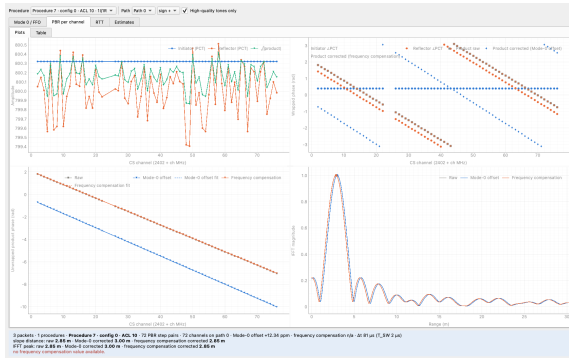
HANDS-ON

TEAM-BASED

DESKTOP APP

NO SOLDERING

Outline of the content **ONE PAGE**



Current application: amplitude, phase and IFFT range profile. Screenshot uses synthetic packets; it does not demonstrate RF accuracy.

LEARNING OUTCOMES

- Distinguish a pairwise range, a position and a track.
- Explain PBR, RTT, frequency calibration and Modes 0–3.
- Relate CS scheduling and RAS traffic to the LE link budget.
- Configure a link and check reported settings and capabilities.
- Compare estimates using quality, corrections and a reference.
- Run, save and replay a controlled one-factor experiment.

180-MINUTE AGENDA

TIME	FORMAT	CONTENT	OUTPUT
0–15 min	Presentation: context	SensWear platform; indoor ranging versus positioning; two-board setup; app installation check.	Experiment goal and system roles.
15–45 min	Presentation: principles	LE connection; PBR, RTT and frequency calibration; antenna paths and multipath.	Predictions about range observations.
45–75 min	Presentation: procedure	Modes 0–3; channels, steps, subevents and procedures; setup, RAS and optional IPT.	Explanation of measurement and data flow.
75–105 min	Presentation: tool demo	Security; controller timings, MTU and connection interval; Plan, Run, Inspect and Replay; questions.	Understanding of the tool and its measurements.
105–120 min	Break (15 min)	Participant break; instructors prepare the device kits for handover.	Kits ready for the groups.
120–130 min	Hands-on: handover	Give devices to groups; connect the client, explore the tool, apply settings and link to the reflector.	Each group ready to make measurements.
130–150 min	Hands-on: measure	Collect a known-distance baseline; inspect controller reports and compare RTT, phase slope and IFFT.	Baseline measurements and saved settings.
150–170 min	Hands-on: explore	Change orientation, add an obstruction or vary one supported setting; inspect the effect with instructor guidance.	Comparison of observations and estimates.
170–180 min	Hands-on: review	Save and reopen the session; record the physical setup and discuss each group's observations.	Replayable recording and a short conclusion.

RADIO PROCEDURE AND IMPLEMENTATION

- **Roles and setup:** LE link establishment, local and remote capabilities, security, frequency-actuation-error information and negotiated configuration.
- **Measurements:** Mode 0 calibration; Mode 1 RTT; Mode 2 PBR; Mode 3 combined timing and phase observations.
- **Budget:** channels, antenna paths, step timings and subevents share radio time; RAS traffic also occupies the connection.
- **Version boundary:** Core 6.0 foundations; Core 6.3 Inline PCT Transfer as an optional extension requiring compatible peers.

ANALYSIS AND REPRODUCIBILITY

- **Match and filter:** paired procedure and step data, channel consistency, antenna path, validity and tone/packet quality.
- **Estimate and check:** raw and corrected PBR slope and IFFT peak; RTT mean/median; bias and repeatability against a known distance.
- **Interpret carefully:** a narrow spread can be biased; the strongest IFFT peak need not be the first path. Zero padding does not improve physical resolution.
- **Keep the evidence:** configuration, controller reports, raw frames, decoded results, session history and run description.

PARTICIPANT OUTPUT

Each team retains a configuration, an HDF5 session, physical setup notes and a short comparison explaining one changed factor. The application can reopen captures and export recordings to MATLAB. The open software and interactive slides support further study of ranging, scheduling and the additional geometry and dynamics needed for wearable tracking.

EXPERIMENT WORKFLOW

Plan	modes, channels, timing
Run	USB initiator + BLE reflector
Inspect	controller reports + raw steps
Compare	RTT, PBR slope, IFFT peak
Replay	saved session + setup notes

The controllers time the radio exchange. The desktop host configures, visualizes, analyses and records it.

Delivery plan

A PLANNED ACTIVITIES / 0.5 PAGE

The session starts with a 105-minute presentation, including interactive phase and timing demonstrations, prediction questions and a walkthrough of the tool. After a 15-minute break, instructors hand preprogrammed device kits to groups of three to four for 60 minutes of hands-on work. Each kit includes an nRF54LM20 DK as the USB-connected initiator and an nRF54L15 DK or Tag as the Bluetooth reflector. Groups connect the devices, explore the application, establish the link and start measurement with instructor support.

Groups first record a line-of-sight baseline at a known distance with a consistent antenna reference point. They compare the reported settings, raw observations and range estimates, then choose a change to explore: rotate the reflector, insert an obstruction or vary one supported schedule or sampling setting. They hold other factors fixed and inspect phase, IFFT profiles, RTT, quality and session events. Instructors help them interpret differences and troubleshoot. The final ten minutes are used to save and reopen the recording, note the physical setup and discuss findings. Calibration and evaluation runs remain separate when a correction is assessed.

- | | |
|----|--|
| 01 | Plan: predict what one setting will change. |
| 02 | Run: acquire a controlled known-distance baseline. |
| 03 | Inspect: compare observations and range estimates. |
| 04 | Replay: reopen the evidence and explain the result. |



Prior SensWear hands-on teaching at Aalto University Summer School.

ACCESSIBLE PARTICIPATION

The activities can be performed at a seated station. The simulator supports setup and analysis practice if hardware is unavailable. Real recordings may supplement the lab when available. Simulator data are labelled as synthetic and are not used to assess RF accuracy.

B RESOURCES REQUIRED / 0.5 PAGE

PROVIDED AND OPERATED BY THE INSTRUCTORS

- **Group device kits:** preprogrammed nRF54LM20 DK initiators with native USB data cables, plus nRF54L15 DK or two-antenna Tag reflectors, power supplies and spares. Kits are handed to the groups for the hands-on hour; kit count will follow registration.
- **Experiment materials:** stable board mounts, measuring tape, distance markers and simple obstructions to make placement and orientation repeatable.
- **Software:** the Python/PyQt6 `ble-channel-sounding` desktop host, integrated planner, simulator, session recording/replay and Getting Started guide. Firmware is prepared before the session.
- **Teaching materials:** interactive slides, app screenshots, baseline configurations and a worksheet for setup notes, controlled comparisons and conclusions. Installation packages will be prepared for local distribution.
- **Platform context:** SensWear hardware for introducing modular sensing, motion sensing and wearable form factors; the core ranging exercises use the documented development-kit setup.

REQUESTED FROM THE VENUE AND PARTICIPANTS

- Projector and screen, instructor table, team tables and chairs, and accessible mains outlets for laptops and board power.
- Space to place each initiator/reflector pair at a measured separation and safely change orientation or insert an obstruction. A surveyed multi-anchor installation is not required.
- One laptop per team (Windows, macOS or Linux), Python 3.10 or newer, permission to install the desktop application, and an available USB data port or adapter.
- Participants install `ble-channel-sounding` and check `--simulate` before arrival. A browser is used for the slides; no programming, firmware build or soldering is required.
- Internet for installation and the current online slides, whose presentation libraries and fonts load from CDNs. The installed desktop app and simulator can run locally.



Instructors

INSTRUCTOR 01 / 0.5 PAGE



SENSWEAR

RF SENSING

AI / ML

Dariush Salami

POSTDOCTORAL RESEARCHER, AALTO UNIVERSITY | RADIO RESEARCH SCIENTIST, NOKIA BELL LABS

Dr. Dariush Salami works at the intersection of artificial intelligence, wireless communication, RF sensing, wearable computing, and embedded intelligence. He received his doctorate from Aalto University for *Spectrum-aware Human-Centric Sensing (HCS) using mmWave radars*, which developed AI- and machine-learning-based methods for human-centric RF sensing. His thesis received an Aalto University Doctoral Thesis Award. His publications span RF localization, mmWave gesture recognition, radar-based human-computer interaction, and integrated sensing and communication.

A former Marie Skłodowska-Curie fellow, Dr. Salami is the CEO of SensWear, an open, modular, and AI-ready wearable platform that exposes raw synchronized data, configurable Zephyr firmware, and interchangeable sensing modules. He has taught in Aalto's Machine Learning D course and teaches wearable-AI concepts through Aalto University Summer School. In this tutorial, he will lead the SensWear platform introduction, measurement principles, desktop application walkthrough, range visualization and controlled ranging activities.

Profile: [Aalto Research Portal](#) | Course: [Introduction to AI-Enabled Wearable Technologies](#)

INSTRUCTOR 02 / 0.5 PAGE



SENSWEAR

EMBEDDED

IoT

Yusein Ali

UNIVERSITY LECTURER, AALTO UNIVERSITY

Dr. Yusein Ali, also published as Huseyin Yigitler, is a University Lecturer in Aalto University's Department of Information and Communications Engineering. He received his doctorate from Aalto University and his B.Sc. and M.Sc. degrees in Electrical and Electronics Engineering from Middle East Technical University. His doctoral thesis, *Narrowband Radio Frequency Inference: Physical Modeling and Measurement Processing*, studied how received-signal-strength measurements from commodity narrowband radios can reveal human location and activity, with particular emphasis on device-free localization and physiological monitoring.

His research spans RF sensing, localization and tracking, ambient backscatter communication, IoT, radio-resource management, wearable mmWave sensing, and multi-antenna systems. He combines this research background with substantial practical experience in commercial embedded systems and teaches Basic C Programming and Embedded System Programming of Communication Devices at Aalto. He is leading the development of SensWear as the CTO of the company. In this tutorial, he will lead the Bluetooth LE and Channel Sounding procedure, controller configuration, timing and data-transfer tradeoffs, experiment design and hardware troubleshooting.

Profile: [Aalto Research Portal](#) | Thesis: [Narrowband Radio Frequency Inference](#)

The instructors combine RF sensing, embedded systems and wearable-platform development with hands-on teaching at Aalto University.